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Born 1826 Died 1894

Honorary Secretary and Treasurer of the Society of Engineers

1854-1894

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ESTABLISHED MAY 1854

Journal and

TRANSACTIONS FOR 1894

AND

GENERAL INDEX, 1857 TO 1894

EDITED BY

G. A. PRYCE CUXSON

SECRETARY

London:
E. & F. N. SPON, 125 STRAND
New York:
SPON & CHAMBERLAIN, 12 CORTLANDT STREET
1895

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PAPERS AND PREMIUMS.

THE Council of the Society of Engineers invites original communications from Members and Associates, as well as from others who do not belong to the Society, on subjects connected with any branch of Engineering.

For any papers that may be considered sufficiently meritorious the Council may at discretion award one or other of the following Premiums, viz.:—

1. THE PRESIDENT'S PREMIUM, given by the President, and consisting of a Gold Medal of the annual value of Five Guineas.
2. THE BESSEMER PREMIUM, given by Sir Henry Bessemer, F.R.S., Hon. Member, of the annual value of Five Guineas.
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The number and value of the Society's Premiums are decided by the Council according to the number of meritorious papers read during the year.

By the Rules of the Society, Members of Council are debarred from receiving Premiums.

PREMIUMS FOR 1894.

At a Meeting of the Society, held on February 4, 1895, the following Premiums of Books, &c., were awarded, viz.:—

The President's Premium (Gold Medal) to:

Tom William Baker, B.A., for his paper on The Utilisation of Town Refuse for Generating Steam.

The Bessemer Premium to:

Edward Carstensen de Segundo, for his paper on Power Distribution by Electricity, Water and Gas.

The Rawlinson Premium to:

Robert Nelson Boyd, for his paper on A Deep Boring near Freistadt, Austria, by the Canadian System.

A Society's Premium to:

Herbert Byrom Ransom, for his paper on the Principles and Practice of Hydro-Extraction.

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ESTABLISHED MAY 1854.

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1895

TRANSACTIONS, &c.

February 12th, 1894.

INAUGURAL ADDRESS.

By GEORGE ABRAHAM GOODWIN, President.

Gentlemen,—My initial and pleasurable duty on taking the chair for the first time as President, is to thank you all for having elected me to this honoured position. The duties of the President of a Society (such as ours) are without doubt very onerous, but this only renders the position more welcome when one has its welfare at heart. It shall be my constant and earnest aim to carry on and leave the affairs of the Society in the same flourishing condition at the end of my term of office as my predecessors have done, and I look forward with pleasure and certainty to the usual active co-operation of the Council in all that appertains to our united interests.

As Mr. A. T. Walmisley, Past President, gave such a full and complete statement of the origin and constitution of our Society in his Address of 1888, I will simply now draw your attention to the fact that this is our fortieth anniversary, and that it is very gratifying indeed to see what steady progress we have made for several years past. Our roll of members has been steadily increasing for some years, which, in the face of recent restriction of engineering work all over the world, is satisfactory evidence of the status which this Society holds, and it is to be noted that our Financial position is sound and thoroughly satisfactory. The total number of Honorary and Ordinary Members and Associates at the end of last year amounted to 522 as compared with 407 at the end of 1888. viz. :—255 Members, 137 Associates, and 110 Foreign Members and Associates, as against 216, 96, and 64 in the former year.

It is with much pleasure that I record the fact that Sir Henry Bessemer has kindly made arrangements to continue in perpetuity his annual five guinea premium which is awarded by the Council for one of the papers read at our ordinary meetings, and also that Sir Robert Rawlinson who was present at our last annual dinner, then signified his intention of also giving a similar premium.

The work of the last dual session has been quite satisfactory and above the average, the total number of attendances being 519 as compared with 493, the average since 1888.

In any large body or society such as ours, it is well known that general progress can only be made and maintained by the energetic co-operation of its individuals, and so I must urge strongly on all Members and Associates to do their utmost by introducing new candidates and preparing papers for reading and discussion.

If only 10 per cent. of us obtained one new member a year, which is I am sure a low assumption, our numbers would rapidly grow and the curve of membership would assume the very satisfactory form I have indicated in red dots for the next three years.

The *raison d'être* of this Society is, in the first place, to hold out a helping hand to our younger professional brethren who will one day have to take up and follow on with our work, to offer them special inducements in taking part in our discussions and meeting them afterwards during the "refreshing interval" when we are always ready to be asked and answer questions.

Secondly, to meet for the reading and discussion of papers on all engineering subjects, which our various members give us from time to time, and which by reason of our generous rules relating to membership qualifications, are not necessarily confined to one branch of mechanical science.

Lastly, to make vacation visits to works of interest, where again the younger members can have brought practically before them the various works that engineers are called upon to carry out.

One very important matter that your Council have been able to carry out, although it has been in contemplation for some time, is the printing *in extenso* beforehand, of the papers read at our ordinary meetings, and which can be had by any one intending to take part in the discussion by applying to the Secretary; by this means, speakers can carefully prepare themselves with notes and references, which of course would tend to increase the value of the discussions.

In February last, our Past President gave an excellent Address and dealt largely on the question of the water supply of London, pointing out that the underground sources were a neglected means of providing an efficient supply and which opinion has been amply verified by the Report of the Royal Commission. He also drew attention to the Kent wells and the geological formation of the country south of London, and drew conclusions that the Chalk was the best, purest, and cheapest source of increase for future supply to the Metropolis. Sanitation was then thoroughly dealt with, and he suggested that the present mode of sewage disposal was not satisfactory, and would not be so, until the daily waste was recovered and returned to the land.

With regard to the papers that have been read and discussed at our monthly meetings during the past year, most of them were of considerable interest. They were as follows :—

(*a*)	"Leicester Main Drainage, &c., and the Construction and Testing of the Sewage Pumping Engines and Boilers"	By Mr. E. G. Mawbey.
(*b*)	"The Cleaning of Tramway and other Rails" ..	,, Mr. H. Conradi.
(*c*)	"Blake's Bridge (Reading)"	,, Mr. E. Burrows.
(*d*)	"Hydraulic Lifts"	,, Mr. R. Carey.
(*e*)	"Gas Substitutes"	,, Prof. V. B. Lewes.
(*f*)	"Collieries and Colliery Engineering"	,, M. R. Nelson Boyd.
(*g*)	"Some Practical Examples of Blasting"	,, Mr. P. F. Nursey.

But as these are now in course of publication, together with the ample discussions upon them, and will appear in our Transactions, I do not propose to detain you by any comments upon them, but I must of course record, that of these the Council decided that Prof. Lewes should have the President's Prize, Mr. Boyd the Bessemer Premium, while Messrs. Carey and Mawbey each received an ordinary Society's Prize.

Our annual outings in the way of summer visits to works of scientific and engineering interest, have this year been well up to the average, and all been of great interest and value to our members and friends who were present. The first trip was to Ramsgate, where we viewed the water and gas works and the new front and harbour improvement works. The water tower was erected in 1878–9, with the object of giving a constant supply and pressure to the town, which up to that date was intermittent. The water is pumped a distance of two miles into the bottom of the tank, which when full, overflows into the low-level reservoir; this entails a certain waste of power as compared to pumping direct into the low-level when the high is full, but I am informed that the cost of fuel is compensated for in other directions.

The gas-works which were next inspected, are a very good example of what such works should be, and in many ways show that great care and forethought have been bestowed on their laying out and subsequent working. There are fourteen benches, each having one central furnace. The latter is on the regenerative system; coke is burnt in a separate furnace below, with a restricted supply of air, causing partial combustion and giving a temperature of about 1000° F. The gases then rise and circulate round the retorts, but first having the necessary amount of air mixed with them, so as to complete the combustion and raise the temperature to about 2300° F. A very simple, but efficient way of economising the fuel used for the distillation of the coal gas, is obtained by raking out the spent coke from the retorts into an iron shoot, placed at an inclination and at right angles to the former, and emptying it into another shoot which carries it into the furnace at the bottom; thus all fuel is charged red hot. Manual mechanical charging and drawing machinery is used on West's system. The purifiers in the ordinary way have a capacity of 750,000 cubic feet, but by the use of Brin's oxygen process their output is raised to 1,500,000 cubic feet, and the illuminating power of the gas is increased 5 per cent.

The front and harbour improvement works consist of a new quay wall on the north side of the harbour, two inclined roads leading, one from York Street to the West Cliff, the other to the East Cliff. The latter, when completed, will give a width of 60 feet instead of 15 feet, and will widen the approach to the London, Chatham and Dover Railway. The rising road to the West Cliff is carried on ornamental arches, party walls being of concrete, varying from 2 feet 6 inches to 3 feet thick at the springing. The arches are of picked stocks 18 inches thick, covered with three layers of pitch and sprinkled with sand and finally filled in with chalk. The harbour immediately in front is to be materially deepened, while another portion too shallow for any practical use has been reclaimed. The total nett cost is estimated at 60,000*l.* and the whole scheme, although it is many years since it was first suggested, has in its present form been planned and carried out by our worthy immediate Past-President, Mr. Valon.

The second of these trips was made on the 5th July to Richmond, when we inspected the New Lock and Weir Works, the Riverside Pumping Station, Wells and Adits.

With regard to the weir works, as these comprise some altogether new mechanical arrangements of a most clever and interesting nature, I feel the time will be well spent if a brief description be given of the scheme and its carrying out.

It appears that about 50 years ago, the river at Richmond had a normal level of about 4 feet 6 inches higher than it is now, one chief cause for the gradual lowering being the ever increasing population of our great metropolis, drawing a continually increasing portion of its water supply from the upper reaches. This has naturally had a very detrimental effect on the otherwise very beautiful piece of the river at this point, disclosing at low water large tracts of muddy and offensive smelling foreshore. It was natural therefore, that the residents should have been agitating for many years to recover the pristine beauties. The object of the work, is to raise the level of the water between the Richmond and Teddington Locks, for some time before and after low water.

The works consist of a foot-bridge 348 feet long, crossing the river at right angles, having five arches, the two outer ones containing a lock and three boat-slides. The three central arches contain the sluices, the invention of Mr. F. G. Stoney, M.I.C.E. These, the largest yet constructed, are 68 feet long and 12 feet deep, and weigh 32 tons each. In design they resemble a bowstring lattice bridge, with cross girders and flat plate flooring underneath them. When down and damming back the water, the structure is horizontal with the flooring vertical, so that the flanges take the pressure due to the stream and head of water, which amounts to a maximum distributed load of 220 tons. The sluices have trunnions at their outer ends and which are carried by steel wire ropes worked from a winch at the top, having four counterbalances of 8 tons each working up and down in wells built in the masonry of the piers. There is only one winch, but the lifting is done at both ends and transmitted by a heavy cross shaft. In the wells are also the guides between which and the prepared ends of the sluices, work a series of live rollers, which although taking the full pressure of water on the sluice, enable the latter to be easily moved at any time, and so much is the friction reduced that from experiments carried out the low coefficient of ·0016 has been obtained (ordinary sluices is about ·6). Besides the counterbalances already referred to, but which only balance the actual dead weight, a series of smaller ones are attached to compensate for the different degrees of immersion of the sluice, so that a perfect balance is always obtained, thus only requiring hand power to move it. When the sluice is lifted up to the top, it is made to turn over by means of a guide roller on it and a fixed guide on pier, so as to take a horizontal position at the same level as the ordinary two side foot-bridges so that no obstruction is caused. To assist in moving the sluice up and down, a mechanical accumulator is cleverly brought into use. This is effected by having a weight of 25 cwt. attached to one end of a steel rope passing over a pulley running loose on one of the shafts of the crab. This weight is hauled up by the man in charge to its topmost position at any convenient time, thus giving a potential energy and capable of being used at will. When required in action it is only necessary to connect the pulley to shaft, when the weight which is allowed to descend winds the sluice up or down, and so effective is it, that the sluice has actually to be raised on the brake and can be lifted in 47 seconds, while to lower by hand alone it takes 7 minutes. The whole of the works have been and are being carried out by Messrs. Ransome and Rapier in a very creditable manner.

The pumping station, although having no special features, was most certainly worth the visit, and many points of interest in the works and in the arrangement and driving of the underground adits were clearly and kindly described in detail by our Vice-President Mr. W. G. Pierce to a large and interested number of our members and friends.

The third and last visit was made on the 11th October when the Tottenham and Forest Gate Railway was inspected. A good many interesting features exist in this line although only 6 miles 4 chains in length. There are seventy-two steel bridges, fifteen being over and fifty-seven under-bridges, all different spans and types. The contract value is 264,422*l.* and the engineer for the line is Mr. A. C. Pain, M.I.C.E.

The science of Mechanical Engineering has now reached a stage of perfection that could not have been anticipated half a century ago. Many of the forces of nature are moulded and diverted and their potential energies transformed into forms where they can be utilised at will to assist man in the various operations required in his everyday life. Not being aware that during any recent period any of my predecessors have dwelt on Mechanical Engineering, I have decided to confine myself this evening to a review of the present position and practice of a few of the chief branches.

BOILERS.

Perpetual motion being impossible of attainment, and as all machines are inert and require some form of motive power or energy to put them in motion, it would appear most rational in the first place to refer to those means whereby the primary source of energy receives its first transformation; I refer of course to boilers or thermal energy transformers.

Modified types of the old wagon boiler were early introduced into steamers, and were used for many years and quite within my recollection, the improvements being in the strengthening of the shells, combined internal furnace and combustion chamber, return tubes and increase of cross and vertical stay bolts. It might be mentioned here, that where stays pass through steam and water spaces undue deterioration always takes place between wind and water.

The next development was Woolf's system, known as "Elephant" type, and which by reason of their being composed of small diameter shells or barrels subjected to internal pressure and externally fired, could be, and are used to the present day for high pressures. The Cornish type followed on, which was soon altered to what is known as the Lancashire. Messrs. Galloway made further advances by inserting across the flue and behind the bridge conical water tubes (small end downwards) connecting the upper and lower levels of the water spaces, thus not only adding more efficient heating surface, but greatly improving the circulation of the water, increasing speed of evaporation and the boiler efficiency. The first of these boilers was used in the Exhibition of 1851. It is stated that one of these earliest types succeeded in evaporating 10·42 lbs. of water per pound of coal, while in one case as much as 11·1 lbs. was obtained, steam pressure being 40 lbs., temperature of feed 100° F. In these boilers it was considered necessary to have ¾ square feet of fire grate for each horsepower, and the rate of combustion was about 10 lbs. of coal per square foot per hour.

Other improvements were made by connecting the two flues into one kidney-shaped combustion chamber well filled and strengthened with conical tubes; in this construction, the fireman is able to stoke each furnace separately, so that when one fire is at its minimum heat the maximum unconsumed products of combustion pass off and mix with the flames and heated gases from the other at its maximum intensity, so causing complete combustion. This is the theoretical idea, but it is to be feared in practice it is not always attained.

In the construction of this type of boiler, the chief points to bear in mind are to have all seams of furnace flues where any exist, below the grate bars, longitudinal joints of shell butted and fitted with covers inside and out, double riveted zigzag, with outer rows twice the pitch of the inner ones. Opinion varies as to which of the covers should be the wide one, but as only the edges of the inner butt straps should be slightly fullered and not caulked, I am of opinion the narrow one should be inside. This most approved form of joint gives maximum strength of plate with certainty of tightness, reliance on which should be made by rivet pressure only. For ordinary draught when say from 20 to 25 lbs. of coal is to be burnt per hour per square foot of fire-grate, the average proportions to allow would be ⅛ square foot of fire-grate per indicated horse-power, 2½ square feet of heating surface, 1¼ cubic foot of water space, and ¾ cubic foot of steam space.

The thickness of shells should be sufficient, so as not to put in ordinary working, more than 5½ tons per square inch on the nett section for steel, and 5 tons for iron, after deducting rivet holes; and if steel is to be used for the shell, it should be of a very mild quality, say of 28 to 30 tons per square inch, with 25 per cent. elongation in 8 inches, and must not be capable of being tempered by heating to a cherry red and quenching in water at 80° F., and on no account should any mechanical work be put upon the material when hot, and at or below a blue heat. Flue or furnace steel should be slightly milder, viz. a tensile strength of say 26½ to 29 tons.

With regard to man and hand holes the best form for these is to flange the shell inwards, face the projecting edge, and on this make the joint with the usual cap and cross stays.

The best arrangement for flues is to take the gases at the back on leaving the combustion chamber and return them along a central flue under the boiler, thence up at the front where they divide, and back again along two side flues to the chimney; by this means the heating is more uniform, the maximum heat abstracted from the gases, and hogging of the boiler is kept at a minimum. Where however, the circulation is good, such as accrues by the use of the Galloway tubes, the gases are best returned first along the sides and back again under the boiler. The earlier forms of flues were plain cylindrical, then came the solid welded with the bowling ring, then the flanged flue with a plain Adamson's ring in between the ends of flues, next Fox's ring corrugations, then the Farnley spiral or screw corrugations, next the Purves type which have thickened grooves, and projections rolled into and on the plates before bending and welding, and lastly the Morrison corrugations, of which the crests meet at a sharp angle, while the depressions are fairly circular, the use of any or all of these being quite up to the best modern practice. The flues should be attached to the end shell plate by internal flanges and although a similar system is frequently used for attaching shell to ends, I consider an external angle iron on at least one end of the shell gives a more elastic connection, and besides which it is helpful to the attachment of the lagging.

Other forms of boilers, that have developed from the Elephant type are the water tube boilers, viz. those where the major portion of the water space is formed by a number of small tubes coupled together in groups and connected to a cylindrical water and steam reservoir at the top, and at the bottom to a mud drum, the most prominent types being Babcock Wilcox, Root, Yarrow, Thornycroft and others. As extreme types of these may be cited the Perkins, Belleville, and Herreschof; the former having a small water space, but the latter practically none, the feed water being flashed into steam as it is pumped in. The Field boiler should also be mentioned, it being in present use chiefly in connection with fire engines.

The earliest form of locomotive type boiler as we know it was fitted to the memorable locomotive engine "Rocket" built by Stephenson & Co. to the designs of Mr. George Stephenson. This engine was the first that had fire tubes passing through the water space of the boiler leading from the fire to the smoke box; it was also the first that used a rectangular fire box, and one of the first having an exhaust steam blast to increase the combustion; and it was undoubtedly due to these three facts that it beat its competitors in the great Rainhill competition in 1829. The importance and value of the simple invention of these fire tubes is incalculable, and has been one of the indirect but most important factors in the opening up of new countries and the spreading of civilisation, as without it the railway system would never have been what it now is, it being beyond dispute that the construction of railways is the first and necessary step for effecting this object. The great advantages of this type of boiler are that a high power can be obtained out of a small capacity, quickness in raising steam, large heating surface, very high rates of fuel combustion possible, quick control over the generation of steam, and safety.

Another and an equally important development of boiler is that known as the marine type, but which can be, and is, equally and economically used on land. These are combinations of Lancashire and Locomotive types; they have large circular shells, with two or more internal flues (generally on one of the corrugated systems), each one connected preferably with its own combustion chamber at the back, the latter being in construction and staying similar to the fire box of a locomotive. From this chamber and passing through the water space of the boiler are inserted a number of fire tubes through which the flames and gases pass from the combustion chamber to the smoke box. The proportion of length to diameter of these fire tubes has a most important relation to each other, extensions of either in either direction affecting their efficiency.

Illustrating this, might be mentioned some most careful experiments which were carried out a few years ago, by M. Henry of the Paris, Lyons and Mediterranean Railway, in connection with locomotives; the tubes varied in length from 9 feet 9 inches to 23 feet, and tested with varying draughts, he deduced that with equal draught the water evaporated per lb. of coal always diminished when the tubes were shortened, but until 21 feet was passed the diminution was very slight, it commencing to accentuate between 16 feet 5 inches and 14 feet 9 inches, but fell rapidly and regularly on going below 13 feet. If, however, the total quantity of water evaporated in a given time from a given weight of coal be considered, then the law is not the same, for when the tubes are shortened below 23 feet the quantity commences to increase and reaches a maximum between 13 feet 1 inch and 14 feet 9 inches, and below 9 feet 9 inches it falls a little below what it was at 16 feet 5 inches. From this it follows that to make a boiler having a maximum evaporating power the tubes should be about 13 feet 10 inches. The remarks previously made as to points to be studied in the construction of boilers are equally applicable here.

With regard to the staying of the rectangular combustion chambers, it is a good plan to make the short stays hollow, so that any crack or flaw in them is at once rendered visible by the escape of water and incrustations in the chamber or outside the shell. This type of boiler is sometimes made double ended, that is to say there are furnaces each end with common combustion chambers in the centre, from which the gases pass in opposite directions and meet again at top in the uptake to funnel; this however is not a good plan as the combustion chambers should not be common to all, particularly to opposite furnaces.

With regard to the nature of the material, Siemens-Martin open hearth mild steel is now generally used throughout, and of the quality already referred to. Sometimes Engineers specify that the furnaces, combustion chambers, tube plates and tubes should be made of iron, but in my opinion, mild steel of regular quality, every plate tested, and having the characteristics before enumerated, is preferable. Steel tubes are not universally approved of, although they are used a good deal in our marine boilers, locomotives and other land boilers. The Belgian State Railways, after several years' trial in their locomotives, have been obliged to return to iron, their experience being that they easily get pitted; this however, may be due to the quality of the water.

A good proportion of heating surface to fire-grate is about 30 to 1, or taking tube surface alone, 27 to 1. Some of the best results obtained from these types of boilers are 10·63 lbs. of water evaporated per lb. of coal from and at 212° F. and having 72 per cent. thermal efficiency. A good average would be about 9 lbs. and 68 per cent.

A very important improvement in the efficiency of this type of boiler has been effected by a Mr. Serve, a Frenchman, who makes the fire tubes with longitudinal, internal, radial ribs, so offering a much increased surface for the absorption of heat from the gases passing through them; they are however only useful with draughts giving a vacuum or pressure of $\frac{7}{16}$ inch and upwards, while at $\frac{3}{4}$-inch pressure Howden's retarders can be usefully added, which is a plain piece of flat steel twisted into the form of a screw, and simply placed in the tubes resting on the ribs, the object being to give the gases a whirling action and making them impinge more directly in between the ribs and surface of the tubes: another advantage is that the scoring action keeps the tubes clean. The gain in efficiency due to these tubes is guaranteed by the makers Messrs. John Brown & Co., to be 10 per cent.

These tubes have and are being used in locomotives with satisfactory results; $2\frac{1}{2}$-inch tubes being used instead of $1\frac{5}{8}$-inch or $1\frac{3}{4}$ inch, giving a larger area through them, less resistance and greater facilities for the liberation of the steam as it is formed, at the same time admitting of more coal being burnt, and as much as 25 per cent. more evaporation being attained. For condensers and coolers, where a rapid and efficient abstracting of heat is required, these tubes made of brass should be of great service.

Still further improvements in water tube marine boilers have been made by Messrs. Thornycroft & Co. and Yarrow & Co., and which after some years of use and experimenting are now accepted by the Government and used in torpedo boats. The Thornycroft design is as follows:—Three cylinders are placed forming the apices of an approximate equilateral triangle with base lowest. The upper one is joined to the two lower ones by two series of small tubes about 1 inch diameter, but depressed in the centre and meeting to form the crown of the furnace, the gases from which return amongst the intermediate open spaced tubes, while the close proximity of the extreme inner and outer rows prevents any direct passage of products of combustion outwards. The Yarrow differs chiefly in having straight tubes connecting the top cylinder to the lower vessels, which latter are made semicircular, the flat side being uppermost and to which the tubes are attached.

The best performances of these are worth recording as showing their efficiency and great power in small compass. The Thornycroft has shown a thermal efficiency of 86·6 per cent., and an evaporation of 13·4 lbs. of water from and at 212° per lb. of coal (87·76 per cent. of carbon), but this at a very low power, viz. 7·74 lbs. of coal burnt per square foot of grate per hour. The same boiler when burning 58·8 lbs. of coal per square foot gave 10·39 lbs. of water per lb. of coal, equivalent to an efficiency of 66·6 per cent. The proportion of heat surface to fire-grate is 61·2 to 1. A Yarrow boiler weighing 5 tons 7 cwts., including water, uptake, funnels, firebars, and mountings, has evaporated 12.500 lbs. or 1250 gallons of water per hour from 50° F. at 180 lbs. pressure, equivalent to 833 indicated horse-power at 15 lbs. of water per indicated horse-power per hour.

There is no doubt that the use of water-tube boilers for steamers has and will steadily increase; large powers can be got out of small capacities, they can be forced without danger, they are light, not only inherently, but contain small weight of water, they are safe, easily controlled and show high efficiency, their chief drawback being that the more the water is subdivided and the larger the powers per unit of weight, the greater care is required in working them and keeping them properly supplied with water.

Many other types of boilers exist, modifications and combinations of those already referred to; for instance, a circular shell externally fired and the gases returning through tubes placed within it and back again through outside flues at haunches, or the shell internally fired with the forward half of flue provided with tubes, combustion chambers inside and outside of shell, &c.; but time will not permit of my going more fully into these.

Feed-heating.

The next point that might be briefly considered in connection with the working of boilers is the question of feed-heating, and here some innovations have been made during the last few years. It is of course of primary importance that all water fed into the boilers should be heated and the more the better, but where such is done before passing the feed pump, its final temperature is restricted, as the vapour given off would interfere with the suction unless it were under sufficient head. Some of the chief advantages of feed-heating are:—

(*a*) It makes a more uniform temperature of water, reduces the wear and tear of boilers that always takes place when relatively cold water is fed into them.

(*b*) Lessens the effect of unequal and local expansion and contraction. Taking a boiler say 20 feet long, having a cold feed, a difference of temperature between top and bottom may exist of say 100°, which would cause a difference of expansion of ·29 inch, and this would be much exceeded when comparing the temperature of the heat transmitting surface of furnace and bottom of boiler shell.

(*c*) Owing to the abstraction by the heater of air and scale forming solid matter the boiler is kept clean. Taking ordinary feed water as containing ·05 per cent. of solid matter, e.g. 35 grains per gallon, and a boiler of 100 horse-power, 1 lb. of solid matter would be deposited per hour.

(*d*) Renders steaming more steady.

Taking the temperature of a hot well as 120° F. in ordinary or compound engines, and a working pressure of steam of 150 lbs., the proportion of the total heat put into it due to the feed is only 7·4 per cent. From this it will be seen how important it is to raise this proportion, as for instance by raising its temperature to 200° F., which is quite possible with ordinary heaters and exhaust steam, the proportion immediately rises to 14 per cent.

There are four types of feed-heaters:—

1. Those that abstract heat from the waste products of combustion.
2. By absorbing the heat in exhaust steam.
3. By using live steam from the boiler.
4. A modification of 2 and 3.

The first two are well known as economisers and exist in several types; for instance, one is composed of a series of tubes placed in the flue immediately after it leaves the boiler, through which the water is drawn into the pump or forced into the boiler, depending on the resulting temperature required. One typical of the second type has a nest of U tubes (free to expand and contract), the exhaust steam entering at one series of the lower ends and discharging condensed at the other, while the feed water is let in at the bottom and out at the top of the shell surrounding the tubes; under this heading also come those known as exhaust ejectors or condensers.

With reference to the third type, it is here that the most remarkable results appear; for at first sight it is difficult to realise how water heated by live steam direct from the boiler (without having done any work) can give any advantages, considering the water so heated is simply returned to the boiler. That advantages and economy however do result from this arrangement, there is no doubt, and very many steamers in our mercantile marine and the Navy, as well as land installations, have it in use.

Experience of many years past has indicated the necessity of keeping grease out of boilers and preventing the formation and accumulation of scale on the heating surfaces, and recently careful experiments on this subject have been made by Mr. A. J. Durston, Engineer-in-Chief of the Navy, from which it appears that the loss of efficiency of some boiler tubes due to deposition taking place simply during the ship's trial trips, varied from 8 to

15 per cent. Other and similar experiments were carried out by heating water under pressure in a vessel placed over a forge fire, when it was found that with clean water the temperature of the water was 344½°, while the hot side of plate was 430°, a difference of 85½°; but when grease was spread over the sides and bottom of the vessel, the hot side of plate rose to 617° F., the water fell to 80° F., a difference of 537° F. Further experiments showed that with higher pressure there was no marked difference in the results.

Heaters mean increased purity of water, but live-steam type particularly so, as the feed can be raised to the necessary temperature so as to quickly throw down almost all depositable matter, such as carbonates of lime and magnesia (by the expelling of the carbonic acid gas) and sulphate of lime. Alkalies up to 46 per cent. cannot be deposited, as they are exceedingly soluble. It is a somewhat common opinion that impurities in water such as those just referred to deposit at boiling-point, but as this is no fixed temperature, but depending on the pressure, it does not sufficiently fix it. The temperatures at which the foreign substances mentioned are deposited are as follows:—Carbonates of lime and magnesia commence slowly at 150° F., but at about 280° to 300° the deposition is rapid (except 2 or 3 grains per gallon which remains dissolved); Sulphate of lime 307°.

The cause of economy in the use of live-steam does not appear to be wholly understood, but opinion seems to lean towards the following reasons:—

1. That the water being hot and freed from air, it more readily takes up the heat transmitted by the furnace plates, notwithstanding the fact that the proportion of temperature of furnace gases to boiler water is slightly reduced by the hot feed.

2. That more steam being generated from hot feed than from cold in a given time, or more steam liberated from a given surface in a given time, the result is the same as if there had been more heating surface.

3. The whole of the heat in the steam is taken up by the feed, whereas if it had been used in an engine, not more than about 12 per cent. would have been utilised, and some would have been lost in the condenser.

4. A pound of coal will do more work in converting hot water into steam than in heating it first and evaporating it afterwards.

By means of these heaters it is possible to raise the feed to within 5 per cent. of the temperature of the feed-heating steam, thus practically leaving the boiler only the duty of evaporating.

The fourth type is one where the exhaust steam from the high pressure or one of the intermediate reservoirs in a triple or quadruple expansion engine is used; and although it is not live steam, it is not a true exhaust. It does not appear on the surface how such an arrangement can be advantageous, as the only extra heat to be obtained, from such steam as compared to using it after exhaust is that, which would have been transformed into useful work in the engine; and further, its abstraction would put the cylinder volumes out of proportion. Again, when steam has once been admitted to the engine, it should be allowed to give up all its useful work there, still leaving the latent heat available after final exhaust.

However, such heaters are frequently used, and with good results, but it is more than probable that their utility is confined to the utilisation of some of the latent heat that would have otherwise been carried off by the circulating water, and the purification of the water with its attendant advantages. The best system of feed-heating, in my opinion, would be to utilise the exhaust steam in a heater on its way to the condenser, thus assisting it, and reducing the quantity of cooling water required, and after the feed so heated had been mixed with the water from the hot well, if a surface condenser was used, it should be pumped through an auxiliary live steam heater to the boiler.

Mechanical Stoking.

Of all mechanical machines, these have perhaps been the most hackneyed; the number of patents taken out being almost endless, and we have much to be thankful for that the survival of the fittest has pushed the inferior ones not only to the wall, but out of sight. It would be invidious on my part, when several good examples exist, to express an opinion as to the merits and demerits of any; good points exist in each, and they all have their special uses. The various types may be divided under two chief heads, viz. Coking Stokers and Sprinkling Stokers, the former relying on a gradual feeding of the fuel from the furnace front to the bridge, the latter on a constant and equal feeding of the coal all over the grate, in exact proportion to the combustion, so that the volume of the fire remains constant.

Coking Stokers.—In these exist the useful means of keeping the fire free from clinkers by the movement of the bars which at the same time feeds the coal. With the object of delivering the coal at a uniform rate and size, all stokers have coal hoppers in front of the boilers, their contents being fed down by rollers smooth or with projections. The coking type may be exemplified by those known as Vickers' and M'Dougall's, the sprinklers by Proctor's and Bennis's.

In Vickers's system the coal is delivered on to the dead plate by alternating reciprocating plungers, after which by alternate backward and forward movements of fire-bars, but always in the same plane, it is gradually fed onwards. The bars which form the chief feature of this machine are only 2½ feet long, and any unconsumed coal or clinker is dropped on to the furnace bottom at the far end, forming a dead end to the ashpit and where combustion is completed. The bridge proper being placed about 4 feet beyond forms a chamber for the complete combustion of the fuel and gases. A small jet of steam is allowed to blow on the ends of the bars which tends to keep them cool.

The M'Dougall stoker is somewhat on the same principle, but provides certain modifications tending to cheapness and facility of repairs. The system of feeding the fuel by the fire-bars is the chief feature of this type. They are divided into two groups, both sets descending at the far end, and coming up to normal level at the near end, working alternately, after which they move forward together.

Sprinkling Stokers.—Proctor's.—As before, a hopper is provided with pushers, but these deliver the slack or fine coal into two shovel boxes, one at either side of the furnace; here radial working shovels actuated by springs project the fuel into the furnace, and being withdrawn to varying distances in cyclic order, deliver the coal at different portions of the furnace. Besides this the back fire-bar bearer carries steam in its interior to prevent burning.

The Bennis type is almost identical with Proctor's and only differs in small details such as the use of crushing rolls and an air dash-pot for regulating the movement of the shovel.

The coking principle is probably more perfect in combustion than the spreading, while the latter also tends to the carrying over of unburnt solid particles of coal. Where constant work is required mechanical stokers of one type or another will give economical results and work efficiently, but where forcing is required without an increase in the draft, their use is not always advisable. One of the great sources of economy of these machines, particularly the sprinkler type, is that fine coal or breeze can be used, and get the same evaporation of water or even a higher one per lb. of coal at a much reduced cost; another advantage is that the fire door need hardly ever be opened except for clinkering, and when movable fire-bars are used even this is not necessary.

In these days when sanitary science has advanced by leaps and bounds, and when a great portion of the community are continually congregating round thickly populated centres, and more and more attention is being given to measures for preventing river pollution, the fouling of potable waters, the emitting of noxious gases, fouling of sewers, &c., it is meet that the prevention of smoke should still further be considered by Engineers and prevented as far as possible by the various Local Boards and County Councils, who have the necessary powers in their hands, as provided for in the Public Health Act, 1875, wherein it states that "It shall be the duty of every "Local Authority to enforce the provisions of any Act in force "within their district requiring fireplaces and furnaces to consume their own smoke."

In the present unsatisfactory construction of our household fire-grates it would be iniquitous however, to enforce penalties against ordinary householders, in fact the Act provides for their exemption, they being practically helpless in the matter. As the efficiency of these grates is as low as 2 per cent. which is the figure stated by Mr. Beaumont at our November meeting, it is surely well worthy the attention of Engineers to study the subject, and design a more perfect and economical arrangement which would have the desirable triple effect, of lessening the consumption of coal, freeing the atmosphere, and largely benefiting the lucky inventor; and it is a matter well worth consideration, if, when new buildings are put up, some compulsory measures should not be taken at an early date to purify our atmosphere. It is computed that about 4000 tons of coal are burnt daily in London, 95 per cent. of which is from domestic fireplaces, containing on an average about 3000 tons of carbon, evidencing at once that it should not be thrown into the atmosphere as solid particles in the form of smoke, but only in the chemically combined state due to perfect combustion as carbonic acid, and when nature can deal with it by diffusing and storing again, until required as food for the vegetable kingdom.

Owing to the peculiar conditions of our climate, a fair amount of rain combined with sudden fluctuations of temperature and height of barometer, and proximity to sea, we have more than an agreeable share of fog, due to the sudden cooling of moisture-charged air. This in itself would not be more than unpleasant, but when such deposition of moisture brings down with it tons of carbon particles in an impure state, saturated with heavy compounds of bituminous and tarry matter, the result is a noxious, injurious and sticky compound, greatly affecting respiration and spoiling all it comes in contact with. The prevention of smoke, besides being a sanitary desideratum, means in most cases a saving of coal, particularly so if brought about by scientific methods of stoking, rather than treating it after it is formed by jets and such like, forced into the furnace.

At the present moment there are probably not less than 20,000 mechanical stokers in operation throughout the country, but there are still a much larger number of Manufacturers who have taken no steps whatever to abate the smoke nuisance, and who still continue to smoke through their chimneys with impunity, needless to say, most discouraging to their neighbouring steam users, who may have incurred considerable expense in overcoming the difficulty. All mechanical stokers are not suitable for application to every boiler, but on proper consideration and selection there would no doubt be found one that would best meet the requirements of quality of coal, draught and duty necessary.

The exemption provided in the Act of 1875, already referred to, applies to cases where the boilers have been fitted with a smoke prevention apparatus, but here the peculiar anomaly sometimes exists, that although smoke may be pouring out of the chimney it is not legally smoking; this naturally tends to prevent further research and developments, while inducing steam users to be satisfied with the cheapest and perhaps most inferior machine, to the exclusion of really efficient ones. There are several apparatuses in the market for simply dealing with the products of combustion after they have been formed, with the view of preventing smoke, but I do not propose, with the limited time at my disposal, to refer to them.

LAND STEAM ENGINES.

It may not be generally known that the first direct application of heat to do work is referred to by Hero in his manuscript on Pneumatics, copies of which are now in the British Museum. These were written in Alexandria about 21 centuries ago and describe an arrangement for opening the doors of temples by the action of fire upon an altar. On the fire being lit, a short period elapsed, during which the prayers of the priests were supposed to be ascending, which when they reached the Deity invoked were responded to by a slow opening of the doors; on allowing the fire to die out the mysterious agency was again invoked and the doors closed. The manner in which this was effected was as follows: the altar was a closed chamber filled with air, from which a pipe passed down, terminating immediately above the level of some water in another closed vessel, from the bottom of which rose a syphon pipe, its other extremity delivering into a bucket or similar receptacle. On the fire being lit, the air in the altar was expanded, descended the tube and displaced the water, forcing it into the bucket, which latter on descending opened the doors by means of ropes coiled on vertical cylinders attached to the hinges, a hanging counterweight at the same time being raised. On the fire dying out the air cooled, the water was syphoned back, and the weights descending returned the mechanism to its original position. This it will be seen contained all the features of the Marquis of Worcester's pump, which dates from 1665, and differed only in the use of steam instead of air.

The development of steam engines during the last few years has not been very marked as regards design and detail construction, chiefly because of their already high state of efficiency, but better workmanship perhaps now obtains, more powerful machinery exists, and so larger engines are now made than formerly. Triple expansion has developed to quadruple, following on the use of steel for boilers and higher pressures of steam. Radial valve gear appears to be displacing the usual eccentric ones, one notable example being the well-known Joy's, which is now largely used for locomotives and marine engines, and the inventor is to be congratulated on having been fortunate enough to obtain an extension of his patent rights. This action of the Privy Council is most satisfactory, as it exhibits their willingness to encourage and assist the meritorious inventor when his invention has not received the reward it deserves. Corliss gears, however, hold their own for moderate speed engines, for mill-driving, both large and small, and for such purposes give very satisfactory results.

This class of gear is particularly convenient when it is required to combine with it governor and knock-out gear, that is, a gear that will break connection between the eccentrics and valve spindles under either of the following conditions:—

(*a*) Governor driving-belt breaking, or governor ceasing to act.

(*b*) Engine racing over a certain speed.

Up to that prescribed speed the governor acts in the normal manner, in other words the gear acts when the governor is in the extreme positions, up or down.

From careful experiments made by the late Mr. Peter W. Willans, whose untimely death all engineers so much regret, it appears that for high-speed compound and triple expansion engines, working at constant load, at all events for his type, there is no great disadvantage or loss of economy by the use of the ordinary butterfly throttle valve, as compared with the more expensive systems of changing the cut off, in fact the disadvantage rapidly decreases as the ratio of expansion at full load increases. When, however, engines have to exert periodical fluctuating duty, such as for power traction or electric lighting, or where the engine is too large for the average work, and where the demand may vary in a few minutes from a lengthened abnormally high to a lengthened low load, then it is of great importance that expansion gear should be fitted, while it is still more of importance in single high-pressure engines as it enables higher pressures to be used with several expansions, as compared with very low pressure used almost non-expansively, at light loads.

The Willans type, through the careful exemplary study and experimental research given to it by its late Inventor and his partners, is perhaps the one that has made the most recent progress. Its application is almost universal, and an electric light station is hardly considered complete without them; they are economical in steam, require small space and foundations, and but very little attention.

From the series of experiments just referred to it was determined that for single non-compound engines working at 55 lbs. pressure and a ratio of two expansions, 25·67 lbs. of water was required per indicated horse-power per hour, while for 3·45 expansions 24·03 lbs. was consumed. In triple expansion and condensing, working at 160 lbs., 12·74 lbs. was registered for a ratio of 12·36, as also for 20·6 expansions, the latter engine being a little less horse-power than the former. The thermal efficiency, viz. ratio of water theoretically required to that actually used, was in the formal trials about 43 per cent. and in the latter 61 per cent. One beautiful law deduced from these typical trials was one now known as "Willans' law," whereby it was shown that in an engine working with constant expansion, the amount of steam used in a given time was a fixed multiple of the horse-power (or mean effective pressure) + a constant; so that the diagram or graphical representation of consumption became a straight line, and at the same time would act as a scale of pressures.

One notable example of a special type of engine which has recently been brought to a most satisfactory state of efficiency is that known as Parsons' steam turbine; from experiments carried out this year by Professor Kennedy on a condensing type attached to a dynamo, he found that 20·3 lbs. of steam was used per electrical horse-power per hour, so that assuming the efficiencies of dynamo and engine each as 90 per cent., the amount works out 16·4 lbs. per indicated horse-power per hour. It is to be noted that this engine carries the expansion of steam to a further degree than has yet been attained, viz. from a pressure of 200 lbs. down to ½ lb. or a ratio of 430 to 1.

The consumption of water per indicated horse-power for first class pumping engines such as made by Hathorn Davey, Worthington, Yates and Thom, and others, is 15·6, 16·2 and 12·2, the latter having been obtained at the Lea Bridge pumping station, the tests of which were carried out by Mr. Longridge and Mr. Bryan Donkin and colleagues, a result I am not aware has been beaten. The quantity used per horse-power hour by ordinary high pressure non-condensing engines can be taken as lying between 25 and 30 lbs., while for condensing 12·2 lbs. as above can be attained.

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The mechanical efficiency or ratio of brake horse-power to indicated horse-power in a well-made engine, can be taken at an average of 85 per cent., a first class semi-portable should give 87 per cent., while for pumping engines, horizontal or inverted triple expansion, 88 per cent. can be obtained. The beam rotative referred to by Mr. Mawbey in his paper gave 89 per cent., while tests made 25th January, 1893, at the Grand Junction Waterworks, Kew, with a Worthington type, have given as high as 94 per cent.

Lastly, the heat efficiency of a steam engine, that is to say, the ratio of the indicated horse-power in thermal units to the thermal heat units taken up by the feed water, will be found to be from 10 to 16 per cent. From these figures and those previously given in connection with boilers, it will be seen that the nett total efficiency of a steam motive power plant, will average only 10 per cent. of the whole heat of combustion, that is to say, that only about one-tenth of the energy in the fuel is converted into useful work.

As an example, take 1 lb. of coal as giving off 14,200 thermal units, then this multiplied by 112 (the usual weight of coal taken as a basis) × 772 the mechanical equivalent of heat — 1227 million foot-lbs. is the product, and taking one-tenth we obtain the figure 122 million, which is just what an ordinary good pumping engine will do.* With regard to fuel consumption per indicated horse-power, it can be anything from 1·3 lbs., depending on class of boiler, engine, and method of working; but here it may be mentioned that this method of stating the practical efficiency of an engine is not by any means definite or useful for comparison, and that the only cases where it is justifiable is in such combined plants as that on steam vessels. The best method of recording fuel consumption is that which has in some cases been adopted by Professor Kennedy, viz. to estimate the percentage of carbon in the fuel and base all calculations upon that; by this means perfect comparable results are obtained, for instance, so many pounds of water evaporated per pound of carbon burnt per indicated or brake horse-power.

I am of opinion that increased thermal efficiency of the steam engine can be obtained by using superheated steam, but at temperatures not exceeding say 600° F., this temperature I arrived at after twelve months' experimenting in the application of superheated steam to locomotives on the Great Eastern Railway, and when no deleterious effects were found to be produced on any of the working parts.

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* *The above "record" result of* 12·2 *lbs. of water per I.H.P. hour, taken in combination with a boiler duty of* 9 *lbs. of water per lb. of coal, and an engine and pump efficiency of* 90 *per cent.—a duty of* 147,240,000 *foot-lbs. is obtained.*

One new and interesting departure in steam engines is the Grafton type, which has been worked out during the past year by Messrs. Easton and Anderson. This engine is designed to run economically at a high speed and with few working parts. The cylinder is open at both ends, with circumferential inlet and exhaust ports cut through the body. There are two pistons oppositely reciprocating therein; the inner, or one nearest the crank, is a trunk, and acts directly and compressively on the centre crank-throw by the usual connecting-rod, while the outer one by means of piston-rod, cross-head and side connecting rods acts in tension on the two outer throws. The latter are at an angle of 135° with the centre one, and the outer piston acts as a slide valve. The effect is an early cut-off and a considerable compression, so much so that it may be made equal to the pressure of the incoming steam and an economical distribution is obtained.

For the high number of revolutions the piston speed works out very low, as they only travel about half what a single one would do, to do the same work. The engine thus becomes single acting as regards each piston, but double acting as a whole. Owing to the short stroke the side pressure due to obliquity of the connecting rod is small. The pistons not moving at all times exactly opposite to each other, the balancing is disturbed, but this is adjusted by weighting the cranks or fly-wheels. A 12-inch engine with an effective stroke of $6\frac{1}{4}$ inches will run at 600 to 650 revolutions, and give 40 indicated horse-power with 100 lbs. steam. Smaller sizes run up to 900 revolutions.

Internally Fired Engines: Gas and Oil.

Considerable progress and improvements have been made of late years in this class of engines. With regard to those worked by gas:—

1. Ignition by slide has been superseded by use of ignition tubes.
2. Self-starters have been devised.
3. Mechanical as well as thermal efficiency has been much improved.
4. Much larger horse-powers are now obtainable from one engine.

The chief systems on which these engines work are:—

1. *Otto or Four Cycle.*—Here an explosion takes place every four strokes or one per double revolution of the crank-shaft, viz. piston advances drawing in the explosive charge, it then returns compressing the mixture; next ignition takes place, the piston is driven forward, and on retiring, finally expels the waste products of combustion.

2. *Six Cycle* (*exemplified by the Griffin Engine*).—Here the cylinder is double acting, each end of it passes through six cycles, viz.:—(*a*) Drawing in explosive charge. (*b*) Compressing same. (*c*) Explosion and expansion. (*d*) Exhausting products of combustion. (*e*) Drawing in scavenging charge of free air. (*f*) Discharging same. From this it will be seen that an explosion takes place at alternate ends of cylinders every 1½ revolution of crank-shaft.

Atkinson Four Cycle.—This engine has the peculiarity that the piston makes four unequal strokes and differently disposed in one revolution of the crank, so it will be seen that an explosion takes place every four strokes, or one per revolution of the crank-shaft, and to this extent it is more satisfactory than the others, but this type is not being further introduced.

Variations or ringing the changes on these fundamental systems have naturally been made by several engineers and manufacturers, as also in regard to the combination of cylinders, so as to give more frequent and uniformly disposed explosions. The Otto principle, however, holds its own, Messrs. Crossley, Tangyes, Andrew, Fielding and Platt, and Robey all use it, but with the addition of several mechanical details, which naturally each consider to be of considerable importance, many of them being no doubt of great value, for instance:—Dispensing with slide ignition valves with their necessary driving gear, which were used to admit and convey the igniting flame to the point at which communication was made to the cylinder, and substituting closed ignition tubes kept hot by Bunsen burners, the length of the tube and the position of the incandescent portion, regulating the point of the stroke at which explosion takes place within fairly accurate limits; exactitude, however, has been obtained by the insertion of a mechanically worked ignition valve placed between it and the cylinders. These tubes are now made so as to last six to nine months. As at different speeds a different period is necessary for exploding, either of two cams has to be used, one for starting and the other for working at full speed.

Self-starters are a natural development attendant on the use of the larger power engines now made, and their existence exemplifies the old saying, that "Necessity is the mother of invention." These are of various forms; the first was brought out by Brayton in 1876, a modern modification of it being one where there is an auxiliary air receiver, which is charged by the engine just before stopping, up to the pressure that the explosive mixture is compressed to in normal working. On starting it is only necessary to put the crank a little beyond the dead centre, turn on the gas until a rich mixture is obtained, next allow the compressed air to enter, and when the correct mixture has been reached, explosion takes place and the engine starts. The chief advantages of such an arrangement are that the air pressure puts the engine in motion and overcomes the inertia just before the explosion, so minimising shocks; it can be started at about three-quarter full load, and the starting explosion takes place within the cylinder.

Another type is one where, after the crank is set forward, the combustion chamber is filled with air, and a little gas is then admitted until the explosive mixture is formed, which is shown by the appearance of a jet of flame. Then on turning off the main the flame passes back into the chamber and the explosion takes place. This arrangement is made to be automatic. Again, a somewhat similar arrangement is one combining both the former; here there is a chamber outside the cylinder, but connected to it with a non-return valve between. The gas is admitted, which mixes with the air previously there, until the required proportion is obtained, at the same time it passes by an aperture into the cylinder; as before, a flame jet is visible and when the gas is turned off at the main it passes back and fires, the pressure being such as to open and pass through the valve into the working chamber in the cylinder, where it is compressed, and another explosion takes place and the engine starts. This external firing chamber is used in still a different form by another maker in the following manner:—

Before stopping the engine, air and gas in predetermined proportion is pumped into the receiver, and, on desiring to start, the crank is put at right angles, the working end of the cylinder is put into communication with the receiver (which is long in proportion to its cross section), a light is applied, combustion takes place, compressing the charge in front and forcing it into the cylinder, where it displaces the air already there, and when the required mixture is obtained, is exploded.

To the engineer accustomed chiefly to steam engines, the large proportion, even at best, viz. at full work, of idle strok to working ones is not at all satisfactory, for several reasons:—

1. The motive gas charge only acts during a small portion of the whole travel of the piston.

2. It necessitates all parts being made sufficiently strong

and heavy to withstand the increased force of explosion that is due to having to develop in one stroke that which should be spread over three or four.

3. The use of heavy fly-wheels, which absorb power in friction in their shaft bearings.

The above are the reasons that mechanicians and engine manufacturers have devoted themselves to endeavouring to get a direct every stroke impulse engine, or to make such a combination of cylinders as will effect this.

Among such developments may be cited the double-acting "Kilmarnock" Otto cycle engine, where explosions take place at both ends of the cylinder, giving two impulses in two revolutions instead of one, but as they follow each other, they both occur in one revolution leaving the other blank; however, by combining two such engines, either tandemwise or side by side, the impulse will take place twice every revolution, exactly as in an ordinary double-acting steam engine.

For ordinary commercial purposes, governing is effected on almost all types of engines by cutting out one or more explosions, but when very steady running is required, such as for driving dynamos, paper and mill machinery, &c., the governor is made to vary the intensity of the explosions within a certain range without cutting out; this, however, entails a slight loss in thermal efficiency. A speed test made with a Moscrop Recorder on a single-cylinder double-acting Kilmarnock engine gave a most satisfactory result, viz. a variation of 2¼ per cent., and at powers varying from normal full load down to one-third. A further improvement has been made by compounding; it, however, remains to be proved that the thermal advantage is not more than counterbalanced by the disadvantages due to complications of working parts and additional friction.

The small powers of gas engines that were used but a few years ago have made enormous advances, and single-cylinder engines are now constructed to develop as much as 120 indicated horse-power, while multiple-cylinder ones, such as the Kilmarnock, have been made to indicate no less than 600 horse-power. One of these engines weighs 53 tons, and has three cylinders side by side, the charges from the two outer ones exhausting and expanding alternately into the central low pressure one, and which has a longer stroke and a higher piston speed than the other two—an obvious advantage.

The starting arrangement for these large engines differs from the usual type, inasmuch as they are put in motion by steam pressure acting at the back end of one of the cylinders, while the front end and other cylinder is drawing gas and giving explosions, after which steam is shut off and gas turned on. As these engines are built to run with generator gas, steam is always available.

The consumption of ordinary illuminating gas in modern made gas engines can be taken as 26 to 20 cubic feet per indicated horse-power per hour for small to moderate powers, while for higher ones it falls to about 18, and for the large powers referred to 15 cubic feet has been obtained, while in the compound type I have been informed that this has still further been reduced to 10. This, if supplied with Dowson generator gas, means only ·8 lbs. of coal per indicated horse-power per hour. As regards mechanical efficiency of this class of engine, it can be taken as varying from 80 to 85 per cent. at full power, and about 70 to 75 per cent. at half power.

The questions of late ignitions and scavenging out are matters well worth special attention; the former by some makers being considered an essential feature of their engines, and it has been stated that increase of horse-power has been obtained thereby; also, by igniting late, less time is allowed for the cooling of the gases by the walls of the cylinders during expansion; and that the engine works smoother than when explosion takes place on the dead centre; in the latter case waste of energy is entailed, although a higher initial pressure is reached, due to heating under constant volume.

It has been experimentally proved, that by scavenging, the power of an engine can be increased 10 per cent, or the consumption of gas reduced, keeping the power the same; this then appears to be the direction in which future development of the gas engine is to take place, combined with longer working stroke of the cylinders, double action and higher speeds. With regard to this scavenging, a vacuum pump drawing during the exhaust stroke, or a displacer piston meeting the working one at the end of the scavenging stroke, appear to offer means of a solution. The "Premier" engine effects this partially by passing compressed air through the ordinary air-inlet valve a short time before the end of the exhaust stroke, and which also prevents explosion in the exhaust pipe. This arrangement would appear particularly useful when working with Dowson gas. While, in 1860, the efficiency of the gas engine compared with the thermal value in heat units of the exploding charge w s only 4 per cent., in 1887 it had advanced to 18 per cent., while now it has risen as high as 26 per cent.

As showing how the heat units are apportioned in this class of engine, it may be stated that the amount lost in the jacket or cooling water will average 35 per cent., while that rejected in the exhaust is about 37 per cent.

The very latest development in this class of engine is one that although not yet brought out before the public, I have been fortunate enough to investigate and see in operation, and as it contains several new features and clever mechanical contrivances, I am sure a few minutes devoted to its description will be of interest and value. In the first place, these engines are of the high-speed type, and in the second, are of positive action, e. g. the point of release and ignition is fixed and cannot vary. They are made vertical, of the Otto cycle and in two types:—

1*st Type.*—The motive power cylinder is carried on the top of a closed crank chamber, through which passes the crank-shaft similar to Willans' steam or Day's gas engine. There are no valves, the piston forming its own. On the face of the crank disc and concentric with the crank-pin is fastened a four-threaded scroll (acting as a pinion with four teeth) into which a worm wheel of sixteen teeth engages, which is attached to the connecting-rod. By this means the piston is rotated once on its axis every four revolutions of the crank-shaft. In the piston are cut two sets of inlet and exhaust ports diametrically opposite to each other, which, coupled with the ports cut through the cylinder, form the valves and seats which open and shut every two revolutions of the engine.

The igniter is a small tube, made of porcelain, projecting almost through the walls of the cylinder, so firing the charge when timed, practically within the combustion chamber. The tube is kept hot by a blow-pipe burner, the air for which is supplied from the crank chamber, the main piston acting as the pump. The fly-wheel is fitted with a radially-acting governor acting on a cam on the shaft, which by its eccentricity adjusts the richness of the exploding charge. One small motor with cylinders 1¾ inch by 1½ inch stroke, worked a sewing machine and ran at no less a speed than 1600 revolutions a minute, and this is mentioned as showing at what high rate such engines can draw in charges, ignite and expel them, viz. 800 a minute.

Another motor of same design, cylinders 5 inches by 5 inches, was working a Crompton dynamo supplying thirty-nine incandescent lamps; its working speed was 700, and when the whole load was suddenly thrown off it only varied about 2 per cent. for but a second or two. The future for these motors, one can venture to prophesy, is assured. The consumption of gas I have not been able to test, but it is to be expected that it will be low, seeing that 80 lbs. compression is used, which not only means an exploding chamber of only one-fifth the total capacity of the cylinder, but also a retention of only 20 per cent. of the products of combustion.

The use of Dowson Producer gas for motive power purposes is now greatly extending both here and on the Continent. That made by the Siemens and other producers generally contains from 60 to 70 per cent. of nitrogen, and although when highly heated by regeneration it answers well for heating purposes, it is not suitable for gas engines, owing to the high proportion of inert gas which tends to lower the temperature of the flame, and render rapid ignition very difficult. Mr. Dowson's apparatus is exceedingly simple, economical and continuous in action, giving a gas with only 45 to 48 per cent. of nitrogen, and with a corresponding increase in the percentage of hydrogen and CO_2, having a good calorific power and capable of being lighted promptly.

He takes a generator containing a good body of incandescent fuel—preferably anthracite coal—but coke will do—passes superheated steam and air through it, the latter for supporting combustion; the former is decomposed, the oxygen arising from it combines with the carbon of the fuel, which first makes carbonic acid (CO_2), but on rising up through the hot fuel is reduced to carbonic oxide (CO), which is a necessity to ensure it shall have a sufficient affinity for oxygen to explosively combine with the oxygen of the air in the gas-engine cylinders, while it must be remembered that every molecule of CO_2 makes two of CO. The gases as delivered from the producer are collected and led through coolers and condensers, after which it is ready for use. 10 lbs. of anthracite yield about 1000 cubic feet of gas, but to which must be added 2 lbs. of coke for the auxiliary steam boiler. Although four times more producer gas is required than when lighting gas is used, still the cost of working large gas engines with this, gives a result not yet attained by any other motive power, viz.—1 lb. of fuel per I.H.P., or, say 1¼ lbs. per brake or effective horse-power, and this manufacturers are prepared to guarantee.

This leads up to the question as to whether the generation of electric light by producer gas worked engines would not in many cases be an advisable and economical arrangement. So far the largest unit of engine power used at central stations is about 300, and as the era for such horse-power in gas engines is fairly on its way, no objection could be raised on that score. The great advantage of such a system is that it becomes easy to vary the generating power so as to accord with the demand without much impairing efficiency, not being subject to those heavy stand-by losses that always occur when steam power is used, by having to keep the boilers under steam and in a state of preparedness.

The undesirable low "load factor," which Mr. Crompton has so aptly named it, e. g. the ratio of work done to that that could be done if everything was working at its full load, can be considered in a somewhat different manner to that in which it is usually taken; for instance, this load factor is frequently taken as the proportion between the sum of work done by those engines at work during the hours *they* had been working, to that that could have been done if all had been working at full load; but this was a method of reasoning rendered necessary by the use of a certain plant, for if say the units of motive power could be chosen as to agree or fairly approximate with the demand, being put in or out of action as desired, and that further, reservoirs from which the working fluid was drawn could be put in or out of action at once, then it would be seen that it would not be correct to say a load factor of 50 per cent. existed, because on the average only 50 per cent. of the engines were at work, for it might have so occurred that these engines at work were so at their full and economical load. Of course this does not refer to a commercial load factor.

Such a plant as described can be closely approximated to by a system of gas producers and engines, the former can be stopped or started by simply shutting off or admitting steam to the producer, and the latter could be increased or lessened as the exigencies of the work required. The waste due to the losses in fuel when the working fluid generators are at rest has been proved to be 10 per cent. in case of steam boilers, and in case of producers the loss is only about 5·5 lbs. per hour for a 300 horse-power plant, and when standing idle.

So far, the internal gas fired engines referred to have been those where the working fluid has been a gas produced by an independent process outside the engine, but another and more direct system is to hand, and that is the use of oil, which occurs naturally in many localities, and which after refining, can be used direct mixed with air as the explosive mixture. Paraffin, petroleum, kerosene and shale oil, obtained by distilling certain kinds of shales can all be used, but require slightly different treatment, but the light oils of simple composition give no trouble. Of late years, several inventors have been studying this branch of mechanical engineering with the result that there are now several good types of oil and petroleum engines on the market.

The chief difficulty has been in arriving at the best system of vaporising the oil so that when mixed with air it shall make a good and easily ignitable mixture, and not leave a residue in the working parts of tne engine. There were several early types of these liquid fuel engines, but it was left for Messrs. Priestman in 1888 to be the first to introduce theirs, and which was worked on the Etève patents. Their method of obtaining the explosive vapour is passing air and a jet of oil regulated by the governor according to the power required, through a special spraying nozzle, the air having a re-entrant motion which very finely breaks up the oil. The mixed spray then passes into a vaporising chamber heated by the hot exhaust gases from the engine, which mixed with a further quantity of air, also regulated by the governor, passes into the motor cylinder where the ordinary Otto cycle takes place. Ignition is made by electrically heating a small platinum wire inside the working cylinders, the timing being done by contact pieces worked by the eccentric rod. It is a curious fact that a small portion of oil condenses inside the cylinder and gives all the lubrication required.

From experiments made by Professor Unwin with Daylight and Rosselene oil (for analyses see Appendix No. 1) used in a Priestman engine, it appears that a mechanical efficiency of 82 to 91 per cent. was obtained (but which latter appears unduly high). Oil used per I.H.P. per hour was ·69 and ·86 lbs. respectively, or ·84 and ·94 ditto per B.H.P., while the total thermal efficiency was 13·31 per cent. Loss of heat in cooling water 47·54 per cent.; loss of heat in exhaust gases 26·72 per cent.

The largest engine made up to date is 90 I.H.P., 35 horsepower having been in use for some time.

Other types of oil engines are those such as the Trusty, Capitaine, Crossley, and Hornsby-Akroyd. The three former do not spray the oil, but vaporise it. The Trusty engine, on the authority of Mr. Beaumont who carried out some experiments, used ·96 lbs. of oil per B.H.P. hour, and ·7 lbs. per I.H.P., while the mechanical efficiency was 72 per cent. Other efficiencies were thermal 14 per cent.; heat lost in jacket water 19·3 per cent. The Hornsby-Akroyd type has the oil injected into heated air under pressure in a red-hot combustion chamber, where it is burnt. The use of petroleum for motive power and heating purposes has no doubt a very large future; the latter use will, however, be referred to later on. Although so far its use has been eminently satisfactory, and gives good and economical results, it appears to me that it cannot yet hope to compete against a Dowson-worked gas engine as regards *pure cost of fuel*, for taking coal at 12*s.* a ton or ·064*d.* per lb., this equals the cost of generating 1 I.H.P. on that system, while for oil, to have the same value and taking the best result so far obtained, its price would have to be ·74*d.* a gallon. These remarks take no cognisance of cost of plant and supervision.

Marine Engineering.

One of the most important and very interesting developments in Mechanical Engineering is that to be found in connection with our mercantile marine, that great and marvellous system of transport from country to country, whereby has been built up that world-wide commercial fame of this Kingdom and our Colonies. With the view of illustrating recent progress it will be sufficient to refer to simply a few of our chief lines such as the Cunard, White Star, Inman (now the American), and the P. and O.

The first steamer of these was the *William Fawcett*, which the P. and O. Company built in 1829, a paddle vessel built of wood, 74 feet long, 10 feet beam, and 206 gross tonnage, speed 6½ knots; the engines were side lever of 60 N.H.P., working at a steam pressure of 6 lbs. per square inch, and of this a large portion was derived from the condenser. The next was the *Iberia*, 1837, also a paddle, but 134 feet long, 24 feet beam, and of 500 tons displacement, speed 8 knots; side lever engines of 300 horse-power were used, steam pressure 7 lbs., and 30 tons of coal a day were consumed or 5·6 lbs. per I.H.P. per hour.

In 1840, the Cunard Company put on service its first vessel, the *Acadia*, 207 feet long, 34 feet beam, 2050 tons displacement, speed 8½ knots, paddle, side lever engines, jet condenser, steam pressure 10½ lbs. giving 740 I.H.P., using 4·7 lbs. of coal per hour. There were four flue boilers, having twelve furnaces, and burnt 16 lbs. of coal per square foot of fire-grate per hour. In 1850 the Inman Company came on the scene with their first steamer, the *City of Glasgow*, which was an iron ship 227 feet long, 33 feet beam, 1600 tons displacement; two lever beam engines working at 10 lbs. steam pressure, and of 810 I.H.P.; here a screw propeller was used 14 feet 3 inches diameter and 18 feet pitch, but geared down to engines by pinion and wheel; the consumption of coal was 3·8 lbs. per I.H.P. per hour. The vessel had three tubular boilers, having nine furnaces, burning 12 lbs. of coal per square foot of fire-grate per hour.

In 1870 the White Star commenced their service with the *Oceanic*, an iron vessel, 420 feet long by 41 feet 3 inches beam, 3707 tons, speed 13 knots. Here a screw propeller was also used 21 feet diameter and 28 feet 6 inches pitch. The engines were compound surface condensing, which at 60 lbs. working pressure gave an I.H.P. of 3500, consumption of coal being 2 lbs. per I.H.P. per hour. There were 12 single-ended rectangular iron boilers, 2 furnaces to each, and 14·17 lbs. of coal were burnt per square foot of fire-grate per hour under natural draft.

It will be sufficient now to refer to the latest steamers that have been put into active service on the Transatlantic route, and these are the world-renowned *Campania* and *Lucania*, sister ships of no less a length than 600 feet, 65 feet beam, 43 feet deep, and of 12,950 tons displacement. These magnificent ships, which are simply floating palatial hotels, replete with every modern convenience in the way of comfort, light, ventilation, &c., with the acme of safety, have both broken the records, one on the western trip, and the other on the eastern, viz. the *Lucania* steaming from Daunt's Rock to Sandy Hook in 5 days 12 hours 39 minutes, while the *Campania* has made from Sandy Hook to Daunt's Rock in 5 days 12 hours 7 minutes, the highest daily speed—allowing for difference of longitude—being 602·6 miles, or 25·08 miles an hour made by the *Campania* on 1st November last year.

These vessels are of steel, have longitudinal watertight bulkheads, as well as transverse ones, rendering them practically unsinkable, have twin screws worked by two sets of triple expansion surface condensing engines, each set having 5 cylinders, two high pressure 37 inches diameter, one intermediate 79 inches, and two low pressure, 98 inches, all having 5 feet 9 inches stroke; the working boiler pressure is 165 lbs., giving an I.H.P. at sea of 27,000, and consumption of coal is only 1·5 lbs. per I.H.P. per hour, but which nevertheless means a daily consumption of the large amount of 450 tons, or $6\frac{1}{2}$ cwt. a minute, a work necessitating 1,832,000 foot-lbs. per day in simply raising the coal the height of the furnaces from the stokehold floor. There are 12 double-ended tubular steel boilers, with 8 furnaces in each, and one single-ended with 4 furnaces, 100 in all, and which consume the coal under natural draft at the rate of 17·5 lbs. per square foot of grate per hour. The cost has been about 650,000*l.* each, and exceeds that of any other merchant vessel.

It may be mentioned here that while one ton of coal in the *Iberia*, 1837, P. and O., propelled 17 tons displacement 221 miles a day, one ton in the *Campania*, 1893, propels 28·8 tons 601 miles a day. Another and perhaps the best way of showing the great advances made in the design of marine engines, although the reduction in coal consumption from 5·6 lbs. per I.H.P. per hour to 1·5 is also very indicative (I have lately heard of 1·17 having been obtained), is that of comparing the capacity of the cylinders to the I.H.P.

The figures for this are as follows:—

		Cub. in. per I.H.P.
Acadia	1840	914
Oceanic	1870	209
Campania	1893	113
Majestic	1889	100
City of New York	1888–9	93·47
Thornycroft 2nd class torpedo boat		9·1

Willans & Robinson's triple expansion engines have a proportion of 36·46 for their 3 V. type, and 13·6 for III. S. type (engine single action). The above figures mean an equally great reduction in the weight of the engines per I.H.P. The chief point affecting the weight of the engines per I.H.P. is the piston speed. In the *Acadia* it was only 270 feet per minute, in the *Majestic* it was 750, while in the *Paris* and *New York* it has reached 900. The following table gives the weight of the propelling machinery per I.H.P. including engines, boilers (filled) and fittings:—

		lbs.
City of Boston	1855	606
H.M.S. *Inflexible*	1878	420
Merchant steamers	1881	480
" "	1891	366
Mail steamers	1893	330
Royal Navy	1881	360
Light cruisers	1881	280
Royal Navy	1893	172
Thornycroft torpedo boats	1881	57
Yarrow torpedo boats	1893	54*
Thornycroft yacht *Gitania*	1876	43·5

For comparative weight of modern locomotives, see p. 46.

While on the subject of engines, I should like to strongly urge the necessity of gauging the thickness of the sides of the A frames whenever such standards are used, and which should be done by drilling small holes in those faces forming the top and bottom surfaces while being cast.

With regard to the terrible breakdown of the *City of Paris*' engines, the cause of the complete collapse has never to my mind been publicly explained, but from personal observation I am satisfied that although the wearing down of the outer shaft bearings was the initial cause of the catastrophe, faulty casting was responsible for the collapse *after* the engines began to race. The broken section of frame I saw—writing from memory—was only about $\frac{5}{8}$ inch on one side, and $3\frac{1}{8}$ on the other.

The first steamship to cross the Atlantic was the *Savannah*, built in New York, originally as a sailing vessel, but steam power was afterwards added. She left the city of Savannah on the 25th May, 1819, and arrived in Liverpool after a passage of 26 days, the engine and paddles being used only 6 days, the latter being unshipped during the remainder of the time so as not to interfere with the sailing, when it was favourable. In 1838, the passages took about 16 to 17 days, but gradually reduced, until the wonderful results already referred to have been arrived at. It is stated that Mr. John Fitch, who placed a steamboat on the river Delaware in 1787, on one occasion said to two friends, "Well, gentlemen, although I shall not live to "see the time, you will, when steamboats will be preferred to all "other means of conveyance, especially for passengers." After his departure, one of them remarked to the other: "Poor "fellow! what a pity he is so crazy."

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* Including all machinery, pipes and propeller.

Nowadays when the question of speed in first class passenger vessels is of so much importance, and when the working expenses are more than proportionately increased thereby, it has become a necessity to find a means of increasing some portion of the motive power plant, so as to give greater power or the same power with diminished space. This desideratum has been found in the application of artifical draught to the boilers, so that whereas with natural draught about 16 to 20 lbs. of coal is burnt per square foot of fire-grate per hour, with artificial draught it has been raised to 30 to 35 lbs., promising to go still further, and this without impairing the thermal efficiency of the boiler, in fact in many cases improving it. This extra duty allows of a lessened number of boilers to be used, lessened working expenses, less dead weight, increased paying passenger accommodation or cargo space and higher speed.

The two chief systems in use are Howden's and the Ellis-Eaves, the great difference being, the former is forced pressure draught, while the latter is suction or induced, therefore continually trying to produce a vacuum.

In Howden's system, nests of short vertical tubes, referred to as the interchanger, through which the waste products of combustion pass, are placed immediately over the smoke boxes and at base of uptake. The space surrounding these is in communication with a casing fixed to the front of the boilers, which is constructed so as to connect by means of valves with the furnace and ashpit, the latter being closed to the open air. A fan is provided, which forces air through the interchanger, abstracting heat from the waste gases and delivering it to the furnaces in any proportion desired. When it is required to fire, the valves leading to the furnaces are closed. This system was first introduced in 1884, on the West India Line, and in 1887 on the Atlantic lines; there are now over 150 ships fitted with it.

In the case of the s.s. *Indiana*, a typical installation of this system, when $22\frac{1}{2}$ horse-power per square foot of fire-grate was given off, that is to say, about 33 lbs. of coal burnt per hour per square foot of grate, the temperature of the waste gases after leaving the interchanger averaged 435° F., while the temperature of air fed to the reservoirs just prior to admission to the furnaces was raised to 190° to 230° F., viz. to within 51 per cent. of the heating gases.

Ellis-Eaves.—This combination is, without doubt, another step in advance, differing from the previous one chiefly in using suction draught, a larger interchanger, and the use of "Serve" tubes in the boiler. The apparatus is arranged as follows:—The interchanger is fixed, preferably immediately over the boiler, the tubes being large and horizontal, communicating immediately with the smoke box at one end and the exhaust fan at the other. The suction or draught created by the fan is in effect natural draught intensified; the pure air is first drawn through the interchanger, where it abstracts the heat from the gases inside the tubes, thence it passes to the furnaces by two side and one central valve, and by two to the ashpit, all adjustable; it then passes through the combustion chamber, tubes, smoke box, and through the tubes of interchanger to the fan.

The advantages of the system lie in the use of the Serve tubes and retarders in the boiler, more efficient interchanger due to larger surface and horizontal tubes, hotter air supplied to furnace, reduced volume of products of combustion drawn away by reason of the reduced temperature, facility in clearing interchanger tubes, cool stokehold, no necessity to shut off draught when firing, and so no danger of flames being forced out of furnace when charging with coal, smoke with ordinary care entirely done away with, and great control over the steam supply. Other advantages common to both are, the higher the rate of draught (within limits), the more nearly does the amount of air consumed approximate to the theoretical quantity required, owing to the better admixture, which means less dead gas to heat up, greater temperature of combustion, with increased efficiency of heating surface, lessened consumption of coal per lb. of water evaporated compared with natural draught, and an inferior quality of coal can be used.

From practical tests which have been carried out, the temperature of waste gases after passing interchanger were registered at 290° to 331° F. when burning coal at about 33 lbs. per square foot of fire-grate per hour, while the temperature of air admitted to the furnace was 246° F., or within 20 per cent. of the heating gases, while when burning from 50 to 60 lbs. of coal, equivalent to 33 to 40 I.H.P. per square foot of grate, these figures became 425° and 295° respectively, and 30 per cent. The best results are obtained when about 35 to 40 lbs. of coal are burnt per hour per square foot of fire-grate, which in the boilers under test necessitated a vacuum at base of chimney of about 4·3 inches of water, or $1\frac{1}{4}''$ to $1\frac{1}{2}''$ in the flues over the fire. The boilers were of ordinary Scotch single-ended marine type, having a diameter and length of 10 feet 6 inches, and had two flue furnaces. The most recent records are those of the steamship *Perthshire*, where temperature of air to furnaces was 216° F., at fan inlet 335° F., in fan room 76°, and vacuum in combustion chamber $\frac{3}{4}$ inch.

The great advantage of suction or induced draught, is, that it is perfectly natural and does not punish the ends of the tubes like forced draught does, and gives less trouble in the combustion chamber, particularly when high rates of combustion are required. I am of opinion that the frequent trouble with leaking tube ends that has been experienced in the Navy and some merchant vessels, has been chiefly caused by using forced draught, where, by reason of the flames being forced along from behind, they are made to lap and press against the ends of the tubes with a blow-pipe action, just at that point where there is most metal, and so least chance of transmitting the heat to the water, viz. the ends where ferruled or expanded and lapped over the plate, whereas suction draught, it has been proved, draws the flame into the centre at the ends, and away from the edges.

Mr. Martin, who read us a paper in 1886 on the subject, demonstrated this; his system was induced draught, but he did not use an interchanger, and had not the advantage of Serve tubes. The consequence was, the fan was not only subjected to the very hot products of combustion, but had to be extra large by reason of the increased volume of the gases due to their temperature, even when using very small diameter plain tubes in the boilers.

It has been stated that leaking tubes are the direct consequence of allowing cold air to enter the furnaces when stoking and clinkering, but I consider this wants further corroboration, and am inclined to believe that it is this to a certain extent, but then only if *combined* with continuous forced draught, such as is obtained in the closed stokehold system. Mr. Durston, already referred to, has proved that with forced draught (closed stokeholds) burning 30 lbs. of coal per square foot of grate per hour, the temperature of centre of tube plate immediately surrounding the tubes attains a temperature 530° F., while if 90 to 102 lbs. are burnt, the temperature rises to about 600° F. I infer however, from some other experiments of his, that where suction draught is used this temperature will be materially reduced, say to 430° F., and this being so low relatively to the furnace gases, even when diluted with cold air, it does not appear likely to be a cause of mischief.

The best practical proof that suction draught can be made to give no trouble at the tube ends, even when carried to such lengths as to burn 114 lbs. of coal per square foot of fire-grate per hour, is the case of locomotive boilers on some of our own railways, and which show that it probably is not the admission of cold air only to the furnace when firing that causes leaky tubes, even in this class of boilers such as used on the Continent, where no fire-brick arches or deflectors are used.

Although not appertaining to the marine branch of mechanical engineering, I would like here to digress for a few moments, and call attention to the advantages that appear possible by the use of the Ellis-Eaves system of draught on land. Boilers, nominally considerably under the power usually required could be used, as by means of the induced draught they could be worked up to 15 to 20 I.H.P. per square foot of grate, with absence of brickwork and its expense; when Lancashire and such like boilers are used, less space is required, and the expensive chimney shafts can be dispensed with, it being simply necessary to have short wrought-iron funnels to lead the products of combustion away.

Smoke also can be entirely done away with, and here I may say, that the possibilities of smoke combustion by such simple means as proper attention to artificial draught, and admission of right quantities of hot air above and below the furnace, depending on nature of coal, offers advantages not yet fully realised.

The initial cost of ordinary Lancashire or flue boilers with brick surroundings and chimney, would probably cost a trifle over the marine type with Serve tubes, interchanger, and fan. The latter would be much more economical in steam production, and probably also in repairs, for which the boilers are always accessible without destruction of expensive brickwork.

Reverting to remarks made in an earlier portion of this address, with reference to central station work, say electric lighting, and where the output of steam has to be controlled rapidly from maximum to almost a quiescent state, this system under review offers exceptional advantages, and would, I venture to think, go far towards materially lessening the stand by losses appertaining to the boiler part of the plant. Lessened ground space and rent, fewer stokers, and other advantages already referred to would also be realised.

It has been proved at sea, that vessels fitted with these systems of boilers, only require half the number, and half the grate area or less, than if they were working under natural draught, the advantages being, reduced dead weight, an economy in coal used, and per horse-power, saving in coal bunker space, with proportionate gain in carrying capacity. I am not aware that these systems have been fitted to other types of boilers than marine, but I see no reason why they should not be attached to any type, and give equally good results.

It is of interest to know that the *William Fawcett* P. and O. in 1839 was fitted with suction draught by fan, while in 1853 Sir Frederick Bramwell was on board the Camden and Amboy Railway steamer *Richard Stockton* in America, when he saw forced draught used on the closed stokehold system. Each boiler was in its own house on the sponsons, and each had its own fan fixed on deck and blowing into boiler room. Other systems have existed and do exist for increasing draught, such as jets of air or steam sent into the uptake as inducers, or sent direct into the furnaces or combustion chambers, closed stokeholds and closed ashpits; but as none except the two latter can be considered practically in use, and as they embody no new features, I leave the subject at this point.

Railways.

No less important than the last subject dealt with is that of our railways, for here are embraced most, if not all, branches of Mechanical Engineering, and so closely welded together that it is almost impossible to tell where one ends and the other commences. A short *résumé*, therefore, of railway practice both here and on the Continent will be of interest and of use.

Commencing with the permanent way, we find that the usual type of rail in this country is the bull head, which for many years has been made of steel, and of increasing weight and length, until they now reach 90 lbs. to the yard as used on the London and North Western, Glasgow and South Western, North-Eastern and Caledonian railways, with an average length of 30 feet; the London and North-Western go as far as 60 feet in some instances; this allows of a lessened number of sleepers, chairs, fishplates and bolts.

On the Continent, in fact almost all over the world, we find Vignoles or flat-bottomed rails are universally used; but the chair system is being tried on the Pennsylvania Railway in the United States, and the Mediterranean Railways are thinking of using a 90 lb. bull-headed rail for main lines, and particularly where heavy inclines and tunnels occur. The Chemin de Fer de l'Ouest, France, use 88·7 lbs., while the Paris and Orleans have lately adopted a 93·5 lb., and the Chemin de Fer du Midi, France, have used a 76·6 double-headed rail for 30 years.

Of flat-bottomed ones, one of the heaviest is 104·8 lbs. (termed Goliath), used on the Chemin de Fer de l'État, in Belgium.

The road as made in this country is probably the finest and most permanent in the world, and now almost as perfect as it can be made. The fish-plates are frequently made of angle section, or with a returned flange passing under the rail in the bull section, and outwards in the Vignoles; the angle between the fishing edges should never exceed 60°.

The rails are drilled at the ends and the bolts made of steel; lock nuts do not seem to have made much headway, many Engineers, although acknowledging their use, objecting to pay extra for them, while some consider that even with lock nuts the joints get loose owing to wear taking place between the rail and fish-plates, and between the fish-plates and bolt-heads and nuts, and lastly, by the stretching of the bolt.

With regard to material for rails, Bessemer steel is almost universal, the tests being one to three blows of a 1 ton weight falling from varying heights; the rail, which is generally placed on bearings 3 feet 6 inches apart, must not show any signs of fracture or exceed a given permanent set; in some cases, however, a further test is made by hanging a dead weight at centre of bearings, which in a 90 lb. rail would be 40 tons, with bearings 3 feet, giving a maximum deflection of $\frac{3}{8}$ inch and no permanent set after one hour's suspension.

On the Continent, further tests are made in tensile strength, varying from 31·8 tons per square inch, which is required by the Bavarian State Railways, to 44 tons and 12 per cent. elongation in 4 inches, by the Paris, Lyons and Mediterranean Railway. The 104 lb. Goliath rail has to withstand 1 ton falling 20 feet, 34 tons suspended at centre of 3 feet $3\frac{3}{4}$ inch bearings, curving to a radius of 5 chains, and 38 tons tensile strength with 13 per cent. elongation in 8 inches.

The only point in connection with the double and bull head permanent way which has not been subject to much change, is the method of keying the rails in the chairs, and this appears to be the only weak point in the system. A recent improvement has been made however, in this direction, by the application to each chair of a tempered steel clip, having two flanges, one at either end gripping the vertical horn, while two tongues projecting out on the other side of the clip engage with the key, allowing of any driving up that may be necessary due to unshrunk wood, but preventing all retrogade movement. In some cases the clips and keys have remained untouched until the latter have commenced to rot. The Great Northern Railway are using them freely, as well as other lines both here and abroad.

With reference to carriages, great advances have been made in their construction and accommodation, particularly those belonging to our leading northern lines, contrasting all the more with some of those belonging to the railway companies south of the Thames, who it would appear are vieing with each other to see who can make their carriages hold together the longest with the least expense and upkeep. Some of these might fairly be called "museum trains." This is a questionable policy, as the time must come when a wholesale alteration will have to be made.

The American system of Pulman car does not appear to find favour in this country, but a compromise has been found in the so-called corridor trains, where the separate compartment is maintained of slightly smaller proportions, and having a corridor running along from end to end and at one side of the carriage. Lavatory carriages are now getting fairly common where running long distance express journeys, and second and third class dining cars have now been introduced; and seeing that the catering for the masses always pays better than for the wealthy few, there is not much doubt but that the system will soon spread, and also that third class sleeping-cars will soon be in operation at an excess fare per berth, a little under that for the first class excess.

Carriage lighting up to the time that Messrs. Pintsch and Pope brought out their systems received but scant attention, and any light that made the darkness visible was considered sufficient; and it is to be wondered at, now that these systems have proved so satisfactory and economical to work, that the old troublesome, dirty, greasy oil lamps are still in use, necessitating as they do a large expense for cleaning, filling, renewals of globes, and men for handling in and out of trains, or about three times as much as for gas. A very large number of our railway services are fitted with the two systems named, as also several on the Continent. The cost for fitting cannot be given with any great accuracy, but it might be taken as 5*l.* per lamp, including its proportion of the reservoirs, pipes, gauges, &c.; while the cost of working in this country comes out about two-tenths of a penny per lamp hour, or about half that of oil; maintenance being about 2*s.* per lamp per annum.

The Paris, Lyons and Mediterranean Railway, by supplying hot air to the burners obtain 7 candle-power as against 5½. It is the general custom to fit gas reservoirs to each carriage, but the Bavarian State Railways only have one to each train and that is in the brake van and connected to the carriages by flexible tubes, the cost of the van fittings being 28*l.*

Lighting by electricity in this country makes hardly any progress. In 1889 the London, Brighton and South Coast

Railway had three main line and 13 suburban block-trains fitted, supplied by dynamo and accumulators, the former driven from an axle of the guard's van. The Midland Railway had a similar system, and one block local and one main line train fitted. The Great Northern had four suburban trains with dynamos and accumulators as before, while the London and North Western, only had one block train, supplied with engine and dynamo on locomotive tender, and no accumulators. On the Continent the Chemin de Fer du Nord had one club train, with current supplied from accumulators only, which were charged at a central station.

At the present day the London, Brighton and South Coast have 26 suburban block, and four main line trains equipped, while 10 others of the former are in course of completion, which will make 400 carriages in all. This Company state that electrically lighted trains are more serviceable than gas-lighted ones, that they get 15 per cent. more work from them (carriages), and that the average annual cost of the trains for maintenance and renewals is less than 50*l.* Lamps are 42 volts and last 6 months. The Great Northern have eight trains fitted, but are making no extensions; the life of their lamp is 12 months, and working cost ½*d.* per lamp hour. The London and North Western and the Midland have discarded electricity and exclusively adopted gas as their illuminant. The Glasgow City and District Railway light their carriages automatically when running through tunnels, by current supplied from a central station and collected by contact pulleys attached to the carriages, of which they have 280 fitted. Life of lamp is 900 hours, and cost 3*d.* per unit. The Chemin de Fer du Nord have four express main line trains equipped, the cost of working and maintenance, including 10 per cent. depreciation for accumulators, is ·2*d.* per lamp hour. The Mediterranean Railway are trying a somewhat similar system, the central station being capable of charging 18 batteries of accumulators in eight hours. Two lamps are fitted to each carriage one acting as a spare one; they last 500 hours and work at 18 volts. The working cost, with renewals, is stated to be ·158*d.* per lamp-hour. Lastly, the Paris, Lyons and Mediterranean have fitted 50 carriages as an experiment.

It is not now a universal custom in this country or the Continent to turn wagon-tyres on the treads; the Great Western, London and North Western and Great Eastern Railways here, and the Belgian State and Midi Railways do not machine theirs, while the Great Eastern go further, and do not turn even those for carriages, where they can find an exact and true pair; the outer skin being of a hard nature, they resist wear for a lengthened period.

It is gratifying to note that at last some improvements are being made with carriage heating, the present foot-warmers being a most expensive system, inefficient and unhealthy. The Midland Railway are trying heating by hot water from the engine, a 1-inch pipe passing along the train on one side, and back on the other to the tender, traversing round each compartment *en route*, the circulation being maintained by the water passing constantly through a $\frac{3}{32}''$ hole at the boiler: it is stated there is no perceptible increase in consumption of coal. The fitting of this costs about 14*l.* a carriage. The Great Northern; Manchester, Sheffield & Lincolnshire, and other lines are trying a system of storage heating much used in the States; here storage heaters filled with brine and unfreezable at the temperatures that obtain in this country, are fitted one in each compartment, and it is stated that steam turned on from the engine for 15 or 20 minutes, will after passing a reducing pressure valve, heat up the heaters sufficiently to last five or six hours, so that the flexible couplings are only in action during these periods. Only one connection is made between carriage and carriage, and provision is made for all condensed steam to be automatically drawn off, so danger of freezing is avoided.

At a trial early last year a run of 2¼ hours was made; the temperature at starting and after shutting off steam was 58° F., and at the end of the journey it had only lowered 3°, although the ventilators were open. Temperature outside was 28° F.

Another type of heater is where the waste steam from the Westinghouse brake engine is passed along a pipe under the carriages, and surrounding it is a larger tube through which air is forced by means of cowls at the front end of each carriage, thus the air is warmed, and enters each compartment under the seats, regulated at will by the passengers; the questionable points are the purity of the air when going through tunnels, and the continuity of the heating steam. The cost per carriage is stated to be 5*l.*

The Mediterranean and Adriatic Railways have used a system for some years, somewhat similar to the storage heater just referred to, the cost of which is 32*l.* per carriage. Acetate of soda foot-warmers are used a good deal both on the Continent and by some railways here. The Belgian State Railways have three systems, viz. ordinary foot-warmers, coke stoves and Radlet system; the latter have heaters similar to the storage heaters, but are heated by the insertion of a red hot iron bar, which radiates heat for five to six hours, while on the International trains, steam heating is used, and which is found to be the cheapest of all, but still the engine drivers are allowed 220 lbs. extra coal for eight hours' work.

From statistics kindly furnished by the Paris, Lyons and Mediterranean Railway, who keep very exact records of the cost of the detail workings, I am able to state that with 5300 carriages, 40,000 foot-warmers are in use with 175 heating boilers, and that the annual expenditure per carriage, including cost for working the heating stations, and upkeep and repairs of boilers, pans, trollies for carrying them and the handling of the pans, is 2*l.* 10*s.*

The Chemin de Fer de l'Est have for some time been carrying out most careful experiments at the instigation of their engineer, M. Lancrenon, and appear to have now got a most excellent system. The objects aimed at are to give warmth to the feet, where as a rule the cold is first felt, means to heat as many as 24 carriages, to do away with all possibility of any part of apparatus freezing, maintaining a uniform heat all along train, rapid heating up of carriages, so as not to necessitate the engine being attached to train for any considerable time before starting, and an economy of working; the solution of which has been found in the use of compressed air mixed with the steam, and then circulated round the carriages. This also gets over the difficulty of pipes at the outset getting waterlogged at bends, the air carrying all condensed steam in fine mechanical suspension to the far or dead end, in a similar manner to what takes place in the "steam loop." The couplings are rendered easy to manipulate, each carriage can regulate its own temperature, to one of three intensities.

LOCOMOTIVES.

In 1829, Messrs. Stephenson and Co. constructed the historical "Rocket" which gained the 500*l.* prize at the Rainhill competition in that year; its greatest speed then was 29 miles an hour, though some years afterwards it ran 4 miles in 4½ minutes, or at the rate of 53 miles an hour. This engine was the first that had tubes traversing the boiler (of which there were 25, 3 inches diameter) and exhaust steam passed into the chimney to create a draught. The boiler had 6 square feet of grate area and 138 square feet of heating surface. The engine empty weighed 3¼ tons and full 4¼. Its traction force per lb. of mean pressure in the cylinders was 18·7 lbs.

The engines of to-day are frequently over 40 tons weight, have 18 to 20 square feet of fire-grate, and from 1045 to 1380 square feet of heating surface, while 45 to 53 miles an hour is an everyday speed for express trains. As an instance of what a prodigious speed can be obtained, I may mention the case of a train on the New York Central and Hudson River Railroad, which on May 9th last year, on a journey from New York, made for a particular mile the speed of 102·8 miles an hour, and on the next day 112½. The line at that point is on a falling grade of 15 feet to the mile (·28 per cent.). The train weighed 147 tons, while the tender was 36 and the engine 85 tons; its tractive force being 100 lbs. per lb. of mean steam pressure. Some of our English engines; for example, one type of the Midland goods, go up to 134 lbs., while some of the London and North Western compounds have a starting tractive force of 177 lbs. per lb. of mean steam pressure.

Some of the recent developments are the almost general use of steel for the frames and boilers, the latter allowing of higher pressures of steam, up to 150 and 160 lbs., radial axle boxes, bogie trucks, which enable the engine to take curves with safety at high speeds, at the same time maintaining sufficient weight on the leading axles to give the necessary resisting power to the rails against lateral movement, greatly reducing the wear of the tyres, flanges and rails; larger engines as a whole, and improvements in detail are now made, and a well-spread base and careful adjustment of weight on the axles minimises the pitching. The London and North Western are trying experiments with intermediate combustion chambers in between the fire and smoke-boxes, and the Mediterranean are applying "Lentz" furnaces, which are practically the substitution of Fox's corrugated boiler flues with a suspended brick arch, for the ordinary fire-box.

One matter that has in my opinion not received the attention it is worthy of, is the balancing of the slide valves, as the power required in working these at the high pressures and speeds is very great; a proof of this is the fact that many of our modern locomotives are fitted with screw or steam worked reversing gear.

Other details that frequently give "leaking" troubles are the fire-door and foundation rings; these are made of heavy rectangular section riveted between the inner and outer fire-boxes; to overcome this, I would suggest that one plate, say the outer, be flanged outwards, and the inner one flanged in the same direction and riveted together outside the outer shell, clear of the action of the fire.

Variable blast pipes are now coming into use, one known as Macallan's has a movable hinged top, fitted with two different size orifices, one 30 to 40 per cent. larger than the other. From experiments with 250 engines, it has been found that when the larger orifice is used 3½ lbs. of coal per mile are saved, which means that an engine making 22,000 miles a year (a fair average) will economise 35 tons.

The other is on the ejector vortex principle. The exhaust is made to issue in a thin annular ring, which by the increased surface more effectually exhausts the gases, so giving the required draught with a lessened back pressure on the cylinders; the entrance to the central space forms a vortex and is placed at the level of the lowermost tubes, so increasing their efficiency and keeping them clear of ashes. The railway company using these, found in 1885, that the whole of their engines were using an average of 29·9 lbs. of coal per mile, while in June last year, the 532 engines fitted with the device were only using 27·9 lbs.; the saving in coal effected since 1885 has been computed to amount to 72,089*l.*

Compounding of locomotives was first suggested by M. Mallet in 1874, while to-day there are probably over 2000 in use, say 80 per cent. on the two-cylinder system, 7 per cent. Webb, 5 per cent. three-cylinder, and 8 per cent. four-cylinder system. The advantages to be derived from their use are:—

1. A better means of carrying the expansion of steam to further limits and so give an economy in fuel, to obtain which higher steam pressures have been necessary, and probably higher yet will be reached. (The Paris, Lyons and Mediterranean Railway are using 213 lbs. per square inch.)

2. A means of increasing the power without increasing the strain on any of the working parts, lessening the angular or torsional strains on the crank-shafts (a most important result), also lessening the shocks on the rails. These advantages can only be obtained however, where more than two cylinders are used (50 increase in tractive force has been attained on the Chemin de Fer du Nord, France, with their 4-cylinder engines on Woolf's system as compared with their latest ordinary type). By admitting high-pressure steam to the low-pressure cylinders an extra tractive force is obtained for starting heavy trains.

In two-cylinder engines, one acts as the high-pressure while the other is the low-pressure.

In the three-cylinder type, two must necessarily be outside the frames and the other inside, generally working on two different axles. Webb makes his third cylinder the low-pressure, while in another system, the two, are the low-pressure.

With four cylinders, they are either used independently or tandem.

The only companies in England using compounds are the London and North Western and the North Eastern Railways. The former have eighty-two running, and more under construction. The low-pressure cylinder has a volume of 2 to 2·29 times the combined volume of the two high-pressure cylinders.

In Ireland, the Belfast and Northern Counties and the Belfast and County Down Railways have had compounds in use since 1891, and it is stated they derive an economy of 14 per cent., while in Webb's 15 to 20 per cent. is obtained. The Great Eastern Railway in 1884 built twelve on the two-cylinder system, but in 1892 eleven of them were altered to non-compound. The Chemin de Fer du Nord obtain 23·28 per cent. of economy in use of steam and 14·45 per cent. in coal.

The average consumption of coal per passenger train mile, for ordinary first-class engines is 30 lbs., or about 1¼ to 1¾ lb. for hauling 10 tons 1 mile. The consumption of coal per square foot of fire-grate per hour varies from 60 to 80 lbs., the Caledonian going up to 114, but this is with Scotch coal, which is inferior to English, for while 1 lb. of coal in ordinary work in a locomotive boiler will evaporate 8 to 9·88 lbs. of water from and at 212° F., the Scotch will only do about 6·69. Comparing the horse-power with the weight of the engine in a similar manner to that referred to in marine engines, we find that one of the London and North Western 6 foot four-wheel coupled non-compound is the lightest, viz. 150 lbs. per I.H.P. including tender, or 85·4 lbs. excluding it, or, deducting the weight of wheels, axles, boxes, springs, buffer-beams and buffers, drawhooks and springs, as not forming part of the engine proper, the weight comes down to 61 lbs. per I.H.P., and 1 ton of coal will propel 26 tons 1040 miles a day. The "Dreadnought" class of compound engine works out 158·3 lbs. per I.H.P. with tender, and 99·61 without.

Feed-heating has not been done much with, and room for development exists, 2½ lbs. of coal having been saved per mile during some experiments carried out by the late Mr. Stroudley when a portion of the exhaust steam was turned into the tender.

On the Continent a good many companies are using compound engines, amongst whom are the Bavarian State Railways, Mediterranean, and the Chemin de Fer de l'Est of France, all of whom use the two-cylinder system. The Chemin de Fer d'Orléans tried, but did not approve of them. The Chemin de Fer de l'Ouest of France, who have had a Webb at work since 1885, are studying another type of four cylinders with bogie in front. The Northern Railway of Spain have decided on four cylinders on the Woolf system; the Paris, Lyons and Mediterranean are firmly fixed on four independent cylinders, and have 110 of these engines under construction; while the Chemin de Fer du Nord have adopted a similar construction, with the high-pressure cylinders outside the frames, and this, after making lengthened experiments with similar engines with inside high-pressure cylinders, the Woolf type, and with three cylinders all working on the same axle.

The fire-grate surface adopted on the Continent is slightly larger than ours, but the Belgian State Railways go as high as 61 square feet; the heating surface is also greater.

The consumption of coal in ordinary engines varies from 27·6 lbs. per passenger train mile on the Zaragoza Railway of Spain, to 37 to 45 on other lines, the average being about 39 lbs. On the Mediterranean line, where two-cylinder compounds are used, an economy of 21 per cent. has been effected. One lb. of coal carries 10 tons 1 mile, while the Northern Railway of Spain state that they do it for ·28 lb. The consumption per square foot of fire-grate varies from 37 lbs. in Mediterranean compounds to 102 in the Adriatic and Midi Railways. The evaporation per lb. of coal averages from 7 to 9·3 lbs.

Wheel centres are now frequently made of annealed cast steel, being found to have less internal strains in them than when made of wrought iron. At Crewe they are cast into rapidly revolving moulds.

It is of course of the greatest importance that tyres and axles should be of a thoroughly good and reliable quality; iron for tyres has now almost been discarded for steel, and the tests that they are put to in this country by the various locomotive engineers are very uniform. Axle tests are, that they should be placed on solid bearings 3 feet 6 inches apart, and subjected to five blows of a 2000 lb. weight falling 20 feet, the axle being reversed after each; besides this the material is tested for tensile strength, and must have an ultimate resistance of 28 to 32 tons per square inch, with an elongation of 25 to 32 per cent. in 2 inches; the Caledonian prefer 25 per cent. in 8 inches, while the London and North Western take 25 per cent. in 10 inches. When iron is used, 22 tons and 25 per cent. is asked for. For carriages and wagons a little harder material is used, viz. 35 to 40 tons and 25 per cent. in 3 inches, but same "shock" tests.

The Continental practice differs somewhat from ours, the material being of a softer nature. For instance, for locomotive axles the blow test is generally 2200 lbs. falling 32 feet and a tensile strength of 27·3 to 31·8 tons, with 28 per cent. in 4 inches, to 25 per cent. in 8 inches. Some of the companies, such as the Paris and Orleans, and the Midi, France, first bend the axle, then straighten it, next deflect it in the *opposite* direction, and finally straighten it. Carriage axles, on the whole, are of the same material, but bending tests are made on the journals, the bodies being held, and the overhanging ends receive the blow. While the usual practice here is to select 2 per cent. for testing, they take 4 to 5 per cent., and so arrange that 1 or 2 represent each charge of steel. A point to note is that tested axles should not be replaced, so that the required number for testing should be rolled extra.

Tyres are generally made of Siemens open hearth steel, but somewhat harder than for axles. Our tensile tests range from 37 to 48 tons, while the extension averages 20 per cent. in 2 inches, the London and North Western going to 20 per cent. in 10 inches. Bending tests by falling weight or pressure are also applied, in some cases the former varying from one-fourth to one-sixth of the external diameter, while the drop test is to let the tyre fall from a given height, edgeways on a solid foundation, the second time at right angles to the first one. On the Continent the steel used is somewhat milder, being 25·4 tons and 20 per cent. in 8 inches for the Paris, Lyons and Mediterranean, to 38·1 tons and 18 per cent. elongation in 8 inches, and, besides which, the general practice is to subject the tyres to a falling weight test varying from a weight of 2200 lbs. dropped 33 feet three or four times, to 1320 lbs. dropped 14 feet 9 inches; tensile resistance being 33 to 45 tons, and 15 per cent. elongation in 4 inches, to 18 per cent. in 8 inches. The Paris, Lyons and Mediterranean ask only for 35 to 40 tons and 15 per cent.

Tyres for carriages and wagons on English railways are made softer than for locomotives, having less tensile strength and more elongation, viz. 32 to 40 tons and 25 per cent. in 3 inches, while on the Continent they have almost the same drop test as the engine ones, but the material is also a little softer, viz. 33 to 38 tons and a slightly higher elongation.

Several of the Continental railways insist on a time guarantee being given by the manufacturers, as well as the tests already referred to; for instance, the Belgian State Railway have a five years' one for all their tyres, and four years' for their axles. If they break within two years, their value, which has been prefixed, has to be refunded by the makers, and after this period, but within the guarantee, the value is put down as half the former.

Copper fire-boxes are the general rule both here and on the Continent, but steel is being experimented with, the greatest innovation in this respect being the system now under trial on the Great Eastern Railway, where twenty-one engines are supplied with mild steel ones only $\frac{1}{4}$ inch thick, and it is found so far that they stand well, and, being thin, transmit the heat readily to the water. As, however, this thickness would not be sufficient for making firm and reliable connections with the tubes, that portion of the box is rolled ½ inch thick, leaving the portion below ¼ inch. No difficulty is experienced with the stays, which are also steel; they are screwed at their ends as usual, and the method of making them tight is both novel and efficient, viz. a $\frac{7}{16}$-inch hole is drilled up the ends for ⅞ inches, and expanded by the driving in of a slightly taper drift; no riveting over of the ends is necessary, the stay projects but slightly into the box, so there is no undue burning. The merit of this ingenious arrangement is to be accorded to Mr. J. C. Park, late Locomotive Superintendent of the North London Railway.

So far petroleum has been but very little used in this country for heating and steam generation, the majority of that imported being used for lighting; but I am strongly of opinion and venture to predict that as soon as the public find the supply is increasing, and can be relied upon at all times and at a reasonable price, a great and lasting impetus will be given in the application of liquid fuel to furnaces.

The practicability of using petroleum or similar oils in locomotives has been amply demonstrated by Mr. T. Urquhart in South Russia and elsewhere, but to Mr. J. Holden, of the Great Eastern Railway, belongs the honour of having first introduced it into this country; Mr. Holden, having had the courage to put his opinion into practice, has fitted thirty engines with his apparatus, which may be briefly described as follows:—

The fire-box, brick arch and deflector are left unaltered, but two 6-inch tubes are put through the back water space, one on each side of the fire-door and just below its level. Into each of these tubes is inserted a fuel injector fitted with a ring for inducing a current of air, which, with the combined annular jet of oil and steam which is used for its injection, is blown in two sprayed jets straight across, and inwardly, under the arch, the two latter crossing each other. The oil is stored in two circular tanks, one on each side of the tender, fitted with warming coils used in cold weather; the tanks will hold 650 gallons, sufficient to carry a train 600 miles. In working, Mr. Holden keeps a thin coal fire about 6 inches thick (an ordinary one being 18 to 24 inches), mixed with lumps of chalk to keep the bars covered, at same time it allows of the jets being turned off at any time when danger signals are up or stopping at stations, with certainty of lighting again as soon as it is turned on. The front ash-pan damper is kept almost closed while the fire-door is kept partly open. A very slight blast being required at the chimney, it has been possible to enlarge the exhaust nozzles 60 per cent., which reducing the back pressure in the cylinders, results in an economy from this cause alone of 3½ lbs. per mile.

The latest comparative tests show the following results:—

		Lbs. per mile.
Average monthly consumption of coal-burning express engines, 18-inch by 24-inch cylinders, 7-feet drivers		35·4
Liquid fuel burning locomotives, same class engines and similar work—	Lbs.	
Coal, including lighting up	11·8	
Liquid fuel	10·5	
		22·3

The advantages of the combined arrangement are:—

1. That with ordinary grate, steam can be easily raised without working injector from an outside source.

2. Fuels can be interchanged according to the state of the market.

3. With thin coal fire the oil can be shut off at will without running risks of chilling fire-box.

4. When standing, the coal fire will maintain steam.

Having had personal experience with this apparatus, I can state that the system works admirably in every way, the degree of adjustment and control over steam supply and pressure being remarkable. On one trip to Ipswich I made, 32 shovelfuls of coal were put on at about 11 minutes intervals, while when returning on a coal engine, the figures were 186 and 4·3.

Iron and Steel Manufacture.

An important branch of Great Britain Mechanical Engineering industry is that of the manufacture of iron and steel, and here a short review will be of interest, although there is nothing absolutely new to chronicle. So far as relates to pig iron, the papers at the last Iron and Steel Institute meetings read by Sir J. L. Bell and Mr. W. Richards give all progress up to date, and are in a convenient form for reference. Following the Thomas Gilchrist process for removing phosphorus, the Saniter one for the removal of sulphur might be briefly mentioned; here the method adopted is to put a finely ground mixture of about equal parts of lime and calcium chloride (the latter a by-product in the manufacture of ammonia and soda) in the bottom of a ladle or receiver, into which the metal is run direct from the blast furnace, a cast-iron plate being put over it to take the shock, the mixture melts, rises up through the molten mass, removing most completely almost all the sulphur present and escaping in dense white fumes. The crude sulphurous pig can also be treated in the basic open hearth furnace or Bessemer converter. 16,000 tons were treated by this process during the past year.

Further, a manganese process for also removing sulphur is now been tried at Hoerde. Into a suitable metal mixer with a capacity of 70 tons, shaped like a converter, is poured sulphuretted pig iron, poor in manganese, after which molten manganiferous pig iron containing a little sulphur, is mixed with it when the metal becomes desulphurised by the formation of a manganese sulphide slag; if these prove ultimately successful, the last worries of steel makers will disappear.

In the manufacture of wrought iron, it might be noticed that while 20 to 25 tons of finished plates per shift was a few years ago considered a good output, 50 to 60 tons is now rolled and sheared in a 12 hours' shift.

In steel making, outputs have enormously increased of late years. The Illinois Steel Company, U.S.A., recently rolled 9640 tons of 60 lb. Bessemer rails in a week, while some of our English mills are following hard on this.

Steel for structural purposes is still chiefly made here by the open hearth or Siemens-Martin acid process, but two or three firms are using the basic; angle irons are rolled at the rate of 120 tons a shift, and nearly 200 tons has been reached, but in this class of work the large number of sections requiring changing of the rolls keeps down the yield. The advance in steel plate output is, however, the most marked.

In the early days of the trade the mills worked single shift, and 12 tons was a good day's work; now a plate mill starting at 6 a.m. on Monday morning does not stop till 3 p.m. Saturday, and has an average output extending over long periods, of 100 tons of sheared and finished material every twelve hours. Two hundred tons in twelve hours has been reached with special effort, and when the class of plate is suitable, 150 to 160 tons has been reached in ordinary work. Naturally large outputs as above conduce to cheap production, but economies are still studied in other directions.

Considerable attention has been given to labour and heat saving, everything which can be done mechanically is so done which enables heavier masses to be dealt with, and minimises accident to workmen. The economy of heat has principally taken the form of providing means for retaining the original heat in the molten steel. Ingots are stripped hot, taken direct to and placed vertical in heating furnaces (vertical handling largely reducing labour), where they remain till the outside skin has become soft and the inside become "set"; then they are transferred to the blooming-mill and bloomed, and in the case of angle irons are rolled into finished bars.

In plate rolling, the hot blooms are sheared to weight, charged hot to the wash heating furnace, and thence taken to the finishing rolls. Thus the fuel required for rolling a ton of ingots to angles has been reduced from 7½ to 1½ cwt., while in plate rolling for slabs and plates it has been lowered from 10½ to 5 cwt.

Great attention is also paid to economy in steam power, and in modern mills, triple expansion condensing engines are used.

Aluminium is freely used in steel casting, and when it can be produced and sold for 2½*d.* per lb. or 23*l.* to 24*l.* a ton, recently promised by a Berlin inventor, it will, without doubt, take the place of ferro-silicon additions in ordinary steel manufacture.

Nickel steel has already taken a place for itself in the making of armour plates, and it may in the future come to be used for boiler plate owing to its high tensile strength and ductility, viz. 40 to 50 tons with an elongation of 10 to 43 per cent. in 8 inches, having 22 to 60 per cent. contraction, and an elastic limit of 55 to 74 per cent., depending on the proportion of nickel.

The addition of nickel makes the metal very fluid, less liable to the liquation of the metalloids, and the scrap of use for remelting without loss of the alloy.

Harvey steel plates might be referred to as a successful combination of ordinary steel making and the old cementation process of making hard tool steel. The plate of mild steel is put into a reheating furnace with what is intended to be the soft side down resting on the sand bottom. The edges are bricked up and walls raised so as to form a trough 9 inches to 12 inches deep above the plate, which is filled with carbonaceous matter and sand on the top. Heat is then applied and maintained for a time, depending on thickness of plate and the depth to which it is desired to harden it by the addition of the carbon. When complete the plate is taken out and tempered, either by running it into a pond, or better, by spraying high pressur water on it. Thus the plate is made to have a hard top, gradually softening until mild steel is reached lower down.

One recent improvement that has been made in the method of casting ingots is that introduced by Mr. James Riley; here instead of the moulds being tapered upwards requiring them being lifted off the ingots, put down, ingots removed and new moulds put in their places, he makes them taper downwards, s that the ingots can be at once taken out and deposited wher required, while the mould is left in position for the next cast so saving a large amount of time, labour and crane power. A much more important point however, is that the top of th ingot which is generally "honeycombed" and "piped," and i the usual system gets the least work put upon it, here, being th largest end, gets most work put on it during the after process of hammering or rolling, while the porous portion in the centre gets squeezed out in manufacture, and cut off as scrap.

On the purely mechanical engineering side might be mentioned a very large and universal cogging mill, designed by the last-named gentleman with the object of not having to turn over the large ingots while being cogged. Two side rolls are used which can be brought together as may be desired; these are of course placed in a different vertical plane to the usual horizontal ones, so that vertical and side pressure can be put on simultaneously during the one pass. The engines are reversible, double cylinder, single acting, non-condensing, 48 inches diameter, 4 feet 6 inches stroke, and give 4000 I.H.P. at 100 lbs. steam pressure. They are geared up $2\frac{3}{4}$ to 1 to the mill by cast-steel helical wheels 18 inches wide, $7\frac{1}{2}$ inches pitch. The second motion shaft drives directly the top horizontal roll, while gearing drives the vertical ones. The horizontal rolls are of cast steel 28 inches in diameter; the top one hydraulically balanced having a travel of 27 inches worked by a small double cylinder marine type engine, which also works one of the vertical rolls in a horizontal direction, the movement being 3 feet. Both the roll and pinion housings are fine samples of founder's work, being of cast steel and weighing 100 tons. The ingots which vary from 2 feet 6 inches to 5 feet in width, and from 4 to $8\frac{1}{2}$ tons, are easily dealt with by means of hydraulic cranes. A hydraulic pusher feeds them into the rolls. In connection with this is a guillotine shears having a blade 5 feet long and actuated by three hydraulic rams, one of 31 inches diameter, the other two of 21 inches, so that three powers are obtainable, first, large ram alone, second two small ones alone, third all together; the total force being 1450 tons at one ton to the inch of rams.

ELECTRICITY.

The incandescent lamps of Edison and Swan have been one of the most useful inventions in this branch of science, as by their use the light has been brought into everyday use and in private dwellings. Three and multiple wire systems have been invented, thereby greatly economising the copper in the mains, the central intermediate ones only transmitting current when the resistances of the lamps on either side differ, and then the amount returned is simply the difference.

Transformers, which until recently gave so much trouble due to the low all-day efficiency, have been greatly improved and the substitution of sub-transformer stations for house-to-house transformers, have overcome the not unfrequent short circuiting and burning out propensity that we heard of some years ago; so it does not appear that the arrangement suggested by a would-be inventor of "*building an underground flue*" for carrying off the products of combustion, is at all likely to be required.

The efficiencies of dynamos and motors are now so high that practically no further improvement may be expected. Step up or down stationary and rotary transformers are now in daily use, the former being only applicable to alternating currents.

The application of electricity to mechanical purposes appears endless, and wherever motion or work is required it can most certainly be used. As a matter of fact, at the present moment it is in use for pumping, hauling, coal-getting, working drills, &c., underground; for taking up the energy of streams or waterfalls, and transmitting it to distances with only moderate loss, to be retransformed into mechanical power; the Niagara Plant being a well-known example where 20,000 volts are to be used in the conductors, and an estimated horse-power of 100,000 in the near future. One advantage in the use of this form of energy when required to do constant work at a distance, say pumping, is that anything wrong at the pump-house is instantly detected at the generating station, by the variation that takes place in the indications of the ampere-meters.

Electricity is also used for working hoists, cranes, travellers and tramways. It is under trial for purification of sewage, and in France and the United States is being used for working canal boats on the overhead conductor system, while for welding purposes a large number of manufacturers have it in daily operation. A recent application of the power is that of using it for riveting machinery, particularly the portable type; here a small motor is attached to the machine to pump the water or other liquid into the hydraulic cylinder, and which can be easily regulated to the pressure required. It might appear at first sight that there would be a loss due to the extra transformation of energy, but this would probably be more than counterbalanced by the fact, that very little power is utilised in bringing the snaps up to the rivets and that it only increases as the resistance increases, while with hydraulic, the full pressure water is used the whole time. Again, metal conductors are much easier to handle than flexible or walking joint pipes, but it remains to be seen if the extra weight involved would render its handling cumbersome.

For the working of passenger hoists this power is most suitable, as only that energy is drawn upon, that is necessary to do the required work, while in hydraulic, the maximum power in terms of water used is always the same, excepting with the multiple power system, a paper on which last year obtained a Society premium and already referred to.

Again, by a judicious weighting of the balance weight, say that equal to the weight of the cage plus half the maximum load, the motor can be made of a minimum size and cost, as the work that would otherwise have to be done during the up journey only, is divided between the up and the down: in the up journey the weight relieves the motor to the extent of one-half the full load, while in the down journey the motor does work equal to that amount; and further, if any passengers should be coming down, their weight reduces the current drawn upon. Such an arrangement has been well worked out by Messrs. Easton and Anderson, who have also made other improvements in connection with the driving and safety gear.

The substitution of electric motors for steam engines and boilers when power is required in districts served by electric light companies, is much to be approved and recommended. To the St. Pancras Vestry belongs the credit of having been first to see the advantage of selling current for day power purposes at a much reduced rate as compared to the lighting one, for not only does it become an economy to the party using such power, but a convenience in cleanliness and in many other ways, while it is a source of profit to the company. For such purposes as newspaper printing establishments, where power is required only for a few hours out of the twenty-four, the economy would be considerable, attendants would be saved, as also the heavy consumption of fuel during the hours of lighting up and firing the boilers, considerable space also would be economised and initial outlay reduced.

I therefore would suggest that all current for power purposes should be sold at the reduced rate whether used by day or night, provided the plant is of sufficient capacity.

One of the most curious and at the same time clever adaptations of electricity is that of using it for magnetic clutches, invented by the late Mr. P. W. Willans, whereby power can be transmitted from shaft to shaft without metallic connection or end thrust. The method of carrying this out, is to fix on one end of the shafts an iron cross head or magnet core with external projections thereon, and on the other an iron ring or wheel with internal ones, only just large enough to permit the former being inserted without actually touching. One of the parts, preferably the inner one, is wound with metal coils through which an electric current is passed, which thus magnetises its core, giving rise to lines of force which, passing through the poles and the armature, set up a magnetic field.

Four of these, to transmit 400 horse-power each, have lately been fitted to the City Lighting Station, Bankside, and proved magnetically satisfactory. Their use applied to gas engines when working dynamos or other machines requiring steady driving, appears peculiarly suitable, as they would practically annul the sudden impulses due to the explosions.

With regard to traction, since the late Dr. Werner Siemens in 1879 first exhibited an experimental electric tramway at the Berlin Exhibition, very considerable progress has been made; while in 1881 the first practical electric tramway was put down near Berlin at Lichterfelde, in 1891 the United States alone had over 5000 cars running 50,000,000 miles annually, carrying 250,000,000 passengers. In 1881 Dr. William Siemens built the first electric railway in this kingdom at Portrush; it is 6 miles long, and the motive power is obtained from a waterfall. It is regrettable that electric traction makes such small progress in this country, presumably because the system of culverts is too dear, third rails as conductors could not be allowed in public highways, and the overhead trolley conductor is hampered by the objections raised to the obstruction of the poles, the overhead wires, and conflicting vested interests. In the heart of large cities, however, these might be valid objections, but it is a question whether the general utility of this system of traction does not far outweigh those disadvantages, seeing it has so far proved economical and satisfactory.

The chief modern electric railway lines in this country are the City and South London and the Liverpool Overhead, which are worked on the third rail system, while the Roundhay and South Staffordshire are surface or tramway lines worked with overhead wires, all of which are working satisfactorily.

The Central Birmingham Tramways Company, who for some years have worked a part of their line by batteries, have decided to change that system, as the cost of working does not at all favourably compare with other electric ones, or even with horse traction.

In Appendix No. II. are given the comparative particulars and costs of working electric railways, and tramways worked by electricity, overhead wire and battery, cable, steam, and horse.

In Philadelphia the City Council are proposing to abolish the cable and substitute the overhead trolley system. They state that the former is not only more expensive, but more uncertain, on account of closing of the slot in cold weather and breaking of the cable.

With such satisfactory results as shown in the table as regards working, there is not much doubt but that electrical energy will in the near future be much used as a means of propulsion, several proposed underground electric lines in this city having already been laid before Parliament, and the necessary powers obtained to allow of their being carried out.

An important conversion from horse to electric traction is now being made in Brussels.

CABLE TRACTION.

Cable haulage for surface railways or tramways is without doubt a most efficient system, showing to best advantage in hilly districts with long stretches of straight roads and large and quick service; in such cases it is superior to all, and cheapest to work. When, however, the roads are sinuous and on a level, with only a moderate service, its advantages decrease. The cost of constructing the road with culverts, pulleys, and providing for drainage, makes it the most expensive system as regards first cost. The system is making headway in this country, although slowly.

At the beginning of last year an important application of it was made on the Brixton and Kennington route, under the direction of our Past President, Mr. W. N. Colam, and it is proposed to extend this to Streatham. Public satisfaction has been earned, and the cost of working has been found to be considerably under horse traction, viz. about 4·5*d.* compared with 8·4*d.* Cable lines have been in successful operation for some years in Edinburgh and Birmingham, the former costing up to June last 6·4*d.* per car-mile, but is gradually getting reduced, while the latter, from the report, shows a cost of 6·32*d.* for cable, 10·12*d.* for horse, 11·22*d.* for steam, and 16·55*d.* for electric battery traction, per car-mile. The Corporations of Glasgow and Edinburgh have decided to introduce it themselves into their cities, while recently the Committee appointed by the Newcastle Corporation have reported recommending the conversion of 22 miles of horse system to cable.

The perfection of grippers has not yet by any means been attained, and considerable room for improvement exists. At present they generally consist of simply two jaws, one movable, which when closed grip the moving rope. They are covered with a soft metal, so that most of the wear takes place on them, leaving the rope intact. What should be sought is one which would allow the car to be started easily and gradually, with a minimum of wear.

In Melbourne about 150 miles of cable tramway have been at work some years, and Sydney is now adopting it, several portions of the machinery having been and are still being made in this country, and for which I am responsible. Two of the largest cable lines have lately been opened, one dealing with the enormous traffic in Broadway, and the other in Third Avenue, New York.

This subject brings to mind the question of wire rope testing, means for which up to the present day are not at all satisfactory. It is seldom that when a whole rope is tested to destruction that it gives a result more than 75 per cent. of the aggregate strength of the individual wires, so this test alone should not be relied upon, but judgment should be based upon the tensile tests of the separate wires, coupled with a twist test in 6 inches or 8 inches, the combination of the two being the best and only sure means of determining whether the material is satisfactory in all respects, and which in my own experience has been most valuable. Several kinds of steel can be made to give high tensile strength or large number of twists, but it is only the best qualities that will give both.

When a rope is at work in, say, a haulage system, or in a suspension bridge, the whole mass is equally strained, but when a short piece is in a testing machine the outer wires do the majority of the work, as is proved by their always breaking first. A strand which is an intermediate combination will give better representative tests than the whole rope. Wire ropes are now very extensively used for lifting, hauling, ships' hawsers, &c., and when they have to pass over small sheaves and barrels they are made flexible by increasing the number of wires, which in the case of cranes are sometimes as many as 270.

WATER POWER.

It is much to be regretted that the surface formation of this country does not permit of more frequent application of water as a motive power. The consequence is that its use makes comparatively little progress here, and such powers as are used are small. There are, however, a few places, such as in Scotland and North Wales, where high falls and powers are obtainable, but as a rule they are far from manufacturing centres, but could probably be made available by transmitting the energy electrically, or using it for some mining or metalliferous processes on the spot. Where very high falls exist, it becomes a question whether they should be used at full head or in stages. The advantages of the latter would be: less strong and costly pipes, less chance of total stoppage due to breakdown of one portion, and facilities for working at different powers economically; while the disadvantages would be: multiplication of stations, with consequent increased attention.

The old water-wheels are dying out, and probably it would be within the mark to say that 95 per cent. of them as they become hopelessly out of repair are replaced by modern turbines. Three fine specimens still exist at Cromford, Derbyshire, where they work the Arkwright Mills, one of the mills being the first in the world that started cotton spinning. Two of these wheels are overshot and one a breast. The former are 25 feet diameter by 10 feet, the other being 20 feet diameter by 17 feet (about 200 horse-power); the third is 18 feet by 15 feet.

There are still a few particular cases where water-wheels would be the most suitable, such as driving slow moving, large diameter mine pumps; they tend to self-adjustment, for as the water becomes scarce they revolve slower. The highest efficiency of breast wheels, reckoning the loss of head in entering and leaving the wheel, is about 68 per cent., while with a well-designed turbine 75 to 80 per cent. can easily be obtained. There are various types of turbines, the following being representative ones:—

The Girard and Pelton, working by impact or impulse, the former by outward flow.

Jonval, by pressure and a through flow.

Vortex, by pressure and impact and inward flow.

The "Pelton" is of all the simplest, but only suitable for high falls. It has bifurcated cups on its rim facing the water, which jets on to them through a nozzle. The stream divides on the divisions, follows the expanding curve of the cups, which combined with the onward rotation of the wheel, is brought gradually to rest and discharged. Its efficiency has been stated to be as high as 80 and 85 per cent., but I consider this wants verifying. Mr. Ellington, who has worked them from his high-pressure mains, equivalent to a head of about 1600 feet, states that an efficiency of over 70 per cent. has been recorded. The other types have fixed or unrevolving guide-blades, and revolving buckets.

Girard.—This turbine allows the energised water to leave the blades and enter the wheel with the full velocity due to the head, it then glides along the concave surfaces of the buckets, leaving the convex faces open to the atmosphere, which is effected by means of holes in the wheel sides; this plays an important part in preventing eddy currents. The buckets are curved re-entrant, and widened, so that the water leaves the wheel with a minimum velocity. As each jet acts by impulse, they are independent of one another, so that by shutting off guide ports on opposite sides of the wheel, to suit a diminished quantity of water or to give a reduced power, the efficiency is maintained; in fact these wheels will work with only a loss of 5 per cent. down to $\frac{1}{4}$ gate or less, and even give good results with $\frac{1}{5}$ gate, the loss being due to the constant friction of the wheel shaft, which becomes relatively larger as the power is reduced. Such turbines are most suitable when the water supply is liable to variation, and if a certain speed is required, the diameter can be made to suit, and partial injection used.

As spent water must be discharged above the tail race, they are not very suitable when it is subject to floods, unless a loss of head can be faced by raising their level. This, however, can be remedied by specially designing.

Jonval.—For medium and low falls these can be used with advantage. Here the buckets are kept fully charged; at their outer edges they are at right angles to the direction of motion, but curved backwards within so that the water is delivered with all its horizontal motion taken out of it, a shallow tail race can therefore be used. This wheel does not give such a high efficiency as a Girard at part gate, but still it is very satisfactory. The adjustment is made by closing the guide ports successively, and not affecting the angle at which the water enters the wheel. It can be worked immersed in the tail water, or above it; the fact that it acts by pressure enables the head that is lost by raising it, to be regained by connecting the wheel to the tail race by a tube, so utilising the vacuum. Two wheels on one shaft can be arranged so that the water leaves on opposite sides, and thrusts are so neutralised. Power for power, these wheels are larger in dimensions than Girard ones.

Vortex.—This is probably the earliest practical form of inward flow turbine in the market. It is made double, viz. the buckets are attached to a central vane, and placed midway between those on opposite sides, which, as in the last, does away with all end thrust. In this motor, the vanes are converging and movable about their ends remote from the centre, and so placed that the water flowing inwards through diminishing passages, acquires considerable velocity and forms a whirlpool or vortex concentric with which is the wheel. The centrifugal force of the water has a self-contained tendency to self-govern, for if the load gets less the velocity increases, and a back pressure in the blades is created, and less water is used, and *vice versâ*. For high falls, such as 600 feet and upwards, this wheel is not suitable and a Girard should be used.

Other types exist, such as the American "Hercules" and "Victor," where the water is admitted parallel to the plane of rotation, and discharged at right angles underneath; here there must be a loss in changing the direction of flow, but at full power they are efficient. In an impact turbine, the velocity of the periphery of the buckets should be half that of incoming water. A 300 horse-power wheel, 300 feet fall, would be about 30 inches diameter.

The power of the turbine is reduced and the shortness of water met, by moving the guide blades in, and reducing the inlet orifices to the wheel. This, however, entails the wheel being relatively too large for the work it may be doing, and when exerting ½ or ¼ power its efficiency is reduced, and more water is proportionately used. The speed of water in the supply pipe should be about 3 to 5½ feet per second. One advantage in this turbine is that the buckets are long, which keep the water a longer time in it, so enabling it to be brought easier and more perfectly to rest than in the other types.

No fixed recommendation can be made as to the best general type, as each installation must be specially considered and that turbine adopted which best suits the major portion of the conditions of working and surroundings.

The largest application of turbines are those now being fitted at the Niagara Falls; they are of the Fourneyron type outward flow, being overbalanced upwards so as to neutralise the downward effect of gravity on all the working parts. Each motor will pass 430 cubic feet of water per second, and acting under a head of 136 feet, will make 250 revolutions per minute, and at an efficiency of 75 per cent. will generate 5000 I.H.P.

DREDGING PLANT.

The first of dredging operations were probably carried out by the Phœnicians 1000 B.C., and who have been credited with the construction of artificial harbours. In more recent times, spoons and buckets manipulated by hand were used, types of which are still to be seen on our small inland rivers and canals. The first dredging apparatus as a machine was made in Italy, but to the Dutch belongs the honour of introducing the first bucket dredger, viz. buckets on a vertical wheel which could be raised or lowered by a screw; our modern chain bucket or ladder dredger is a direct descendant of this.

The first application of steam to such machines was made by Trevithick at the commencement of this century; the engine was about 6 horse-power, and his buckets were of hoop iron, with wood backs, but which soon had to be replaced with stronger ones. About 30 years ago steam hopper barges were introduced and about 10 years later hopper dredgers were constructed combining the duties of dredger, hopper, and tug, so that not only could material be raised, but taken away and deposited.

The chief types of modern dredging machines are:—

(1) Stationary dredgers which discharge into hoppers alongside, which latter can be self-propelling or not.

(2) Steam hopper dredgers just referred to; these have the continuous ladder of buckets, and are most used of all types. By suitable designing of transverse traversing carriages, the bottom tumbler with buckets may be made to project beyond the stem, so that they can be used for cutting their own way through banks or shoals.

(3) Sand pump hopper dredgers: here the dredging is done by a centrifugal pump with its suction pipe put overboard and reaching down to the sand it is required to remove. These are fitted sometimes singly and doubly and can also be fitted as an auxiliary to a bucket dredger. For removal of sand bars, such as at Liverpool, and sand banks, they are extremely valuable. There are several other types, such as dredgers worked by different forms of grabs as in excavators, forced into the ground, and lifted by hydraulic power.

Comparing the dredger in use at Hull Docks in 1808 with a high class modern one, we find the former had a wooden hull 70 feet long, 19 feet beam, and a jet condensing side lever engine, 6 horse-power, as compared with the present day iron or steel hull, 200 feet long, 40 feet beam, a surface condensing triple expansion engine of 1000 I.H.P. and capable of dredging 50 feet below water. The larger bucket dredgers will lift 1000 tons an hour and steam at the rate of 9 to 10 knots; in fact, several are made capable of going under their own steam to any part of the world, and are capable and comfortable sea-going vessels.

Of sand pump hopper dredgers, a fine example is the *Premier*, which was recently built for the Government of West Australia, by Messrs. Smit of Holland, from the specification of Messrs. Coode, Son & Matthews, to whom I am indebted for the following particulars:—

Length, 170 feet.
Breadth, 32 feet.
Depth, 12 feet.
Draft light, 8·5 feet.
Draft loaded, 10·75 feet.
Capacity of hopper, 12,000 cubic feet = 600 tons.
Maximum depth dredged, 40 feet.
Speed fully loaded, 9 knots.
Steam pressure, 160 lbs.
Engines, direct-acting, triple-expansion, surface-condensing.

On the official trial 680 I.H.P. was registered when steaming, and 400 when pumping at her full capacity, which was raising 615 tons of sand from a depth of 40 feet in 13 minutes, or 2838 tons an hour, but as probably the sand as pumped would not exceed 20 per cent. of the combined sand and water, the total weight pumped would be 14,190 tons. The hopper doors are worked hydraulically, the suction pipe is easily raised and housed before the vessel starts for the depositing ground.

When requiring to pump, the suction can be fixed in two minutes. Where the *Premier* is now at work, she is only half a mile from the depositing ground, so able to make six trips a day. In six months 227,000 cubic yards of sand have been raised and deposited, at a cost of 1·7*d.* per cubic yard, and reckoning interest and depreciation 3·3*d.* per cubic yard ; labour and fuel being more expensive than in this country.

The largest dredger, however, of this class yet built is the *Brancker,* built for the Mersey Dock Estate, and I am indebted to Mr. Anthony G. Lyster for the following information :—

Capacity of hoppers 52,520 cubic feet, or 3000 tons of sand at 124 lbs. per cubic foot.

The vessel is designed for, and has filled herself in 45 minutes under favourable conditions.

Depth dredged varies from 20 to 45 feet.

The distance from the bar to one of the depositing grounds is 1½ miles, and the time occupied in going and returning is about 45 minutes.

Horse-power when steaming is about 1400, and when pumping about 700.

The cost during the past three months for raising and depositing has been about 1½*d.* per cubic yard, which includes wages, coal, other supplies and repairs. In the summer months, it is expected this cost will be reduced.

Dredgers for working in a solid rocky bottom without recourse having to be had to blasting have also been employed. A notable and recent instance is that of excavating the new channel leading to the harbour of Alexandria for a width of 300 feet through a mile of solid rock ridges extending out into the open sea. The work was carried out practically without blasting by Messrs. S. Pearson & Co., who are now having a still stronger and more powerful dredger built for similar work in Bermuda. In this machine a strain of 100 tons will be brought upon the lip of every bucket upon its contact with the rock.

Refrigerating Machinery.

The development of this branch of Mechanical Engineering during the last few years has been well sustained, and made rapid headway, particularly the carbonic acid (CO_2) machines. It is after all not many years ago that chemical machines were tabooed and many reasons worked up and given out to show that their use was not advisable. As late as 1887, practically the only type of machine used on board ship was the cold air (their day is nearly over), while now they are even being taken out and replaced by chemical ones.

Chemical machines depend on using a liquefiable gas, which after being compressed in a gas pump, are delivered to a tubular condenser, where under the influence of the pressure and water circulating round the tubes it gives up its sensible and latent heat and liquefies; from here it is allowed to escape through a valve into a refrigerator (of somewhat similar form to the condenser), where it gasifies and regains its latent heat from the surroundings which can either be a circulating brine or the actual objects to be refrigerated. Gases that can be so used are ether, ammonia—either used by compression or absorption, sulphurous oxide, anhydrous ammonia, carbonic acid, &c., the chief ones now in use being the ammonia and CO_2, the latter being non-poisonous and non-inflammable; the best ones are those that have a low specific heat in relation to the latent heat of evaporation.

In the cold air machines, as no liquefaction takes place and no latent heat is given out or taken up, the measure of refrigerating power is the work done in the compressor and the heat carried away by the cooling water; but in the chemical machines, the work done in the compressor is no measure whatever, although it may be some function for a particular refrigerating agent and under fixed conditions. For instance, we find in table of results for a Linde machine trial placed before this Society by Mr. Lightfoot in 1891, that the thermal units absorbed in the compressor vary from ·126 to ·28 of the refrigerator duty.

To show the great reduction in the cost of working the chemical machines as compared with cold air, I may cite the case of the s.s. *Selembria,* which was fitted up under my superintendence, and at that time was the largest installation afloat, and compare it with the most recent one, viz. the s.s. *Gothic.*

The *Selembria* carried 1000 tons or 40,000 carcasses of mutton from the Falkland Islands. There were four 70,000 cubic feet cold air machines, and each required 120 horse-power to work, or 480 horse-power in all.

The *Gothic* has a capacity of 1800 tons, or 75,000 carcasses to deal with, for which there are only 2 CO_2 machines, the I.H.P. of each being 70, or 140 in all, and as these are worked by compound condensing engines, the cost of working is very low.

The thermal units that can be abstracted by each of these machines are 800,000 per hour, while the units accounted for by the steam engine are 179,500. The value of the CO_2 to charge them is only 7*l.* 10*s.* One novel detail in connection with these machines is the safety valve, which is nothing more than a thin disc of carefully prepared sheet copper, screwed down round its edge between two metal surfaces. These are arranged to burst at the desired pressure, which they do within a variation of 2·6 per cent.

It has been stated by some authorities that the critical temperature of CO_2 is 88° F., and that above this it cannot be liquefied, so if used under these conditions in the machine its action would be identical with air, and the efficiency would consequently fall considerably. As a matter of *fact*, however, these machines are in use in India, the Red Sea, Queensland, &c., with water at 100° F., and give satisfactory results, so the statements referred to, appear to require some explanation.

The Linde system uses anhydrous ammonia as the refrigerating agent, which equally with CO_2 has no corrosive effect on steel or iron. The ss. *Perthshire* and *Buteshire*, which have lately been fitted with this plant, have each a capacity of 2400 tons, or 90,000 carcasses; so reliable are these machines considered, that it is intended to bring meat simply *chilled*, from Australia. Their capacity in terms of ice-making is 36 tons per 24 hours.

In 1880 the total quantity of frozen meat imported from Australia was 400 carcasses; in 1885 it rose to 777,891, the imports being from the River Plate and New Zealand particularly; in 1890 the number had increased to 2,948,076, and in 1892 to 3,310,022. The total number of vessels fitted up to end of 1892 have a maximum annual importing capacity of about 6,000,000 carcasses, so there is still a large reserve. In this country 12 tons of ice can always be guaranteed per ton of coal, but if initial expense were no object, this could probably be increased to 20 tons.

Time fails me, and so I am prevented from referring to many other branches of Mechanical Engineering that I had hoped. I deemed it better, however, to confine myself to a few, with the object of discussing them in some detail and giving matter that I hope will be of after value, rather than going over the whole ground and simply culling a few facts here and there, which decision I hope will have your approval.

A sound practical training in workshops is, I consider, a primary essential to any Engineer's training, as it enables the student to take an interest in and thoroughly grasp the objects with which theoretical principles are afterwards taught him. While such practical education is going on he should study in his leisure hours, which in these times of eight-hour days is considerable. To those who decide to take up mechanical engineering I would certainly advise their competing for the Whitworth Scholarships, as all the thirteen subjects forming the competition comprise most necessary and valuable knowledge. For myself, I must own that I have the greatest respect for, and feel under the deepest obligation to, the late Sir Joseph Whitworth, one of whose Scholarships I was fortunate enough to obtain in 1875.

I would ask our young friends to apply themselves diligently to the noble pursuit they have elected to follow, not to rest satisfied with a superficial knowledge, but by a sound elementary groundwork enable themselves to follow up some speciality to the hilt, at the same time obtain and maintain a good general knowledge of other branches; and, in conclusion, would say in the words of Francis Bacon—

> "I hold every man a debtor to his profession; from the "which, as men of course do seek to receive countenance "and profit, so ought they of duty to endeavour them-"selves by way of amends to be a help and ornament "thereunto."

APPENDICES.

I.

Analyses of Samples of "Russolene" and "Daylight" Petroleum.*

(Made by Mr. Charles J. Wilson, F.C.S.)

	Russolene.	Daylight.
	per cent.	per cent.
Carbon	85·88	84·62
Hydrogen	14·07	14·86
Oxygen, &c. (by difference)	·05	·52
	100·00	100·00
Density at 60° F.	0·8226	0·7936
Flashing point (Abel test)	86° F.	77° F.
Calculated value per lb. in thermal units, assuming water produced is gasified ..	19,957	20,198

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* Minutes of Proceedings Inst. C.E., vol. cix. p. 19.

COMPARATIVE TABLE OF PARTICULAR

PARTICULARS.	ELECTRIC RAILWAYS.			
	City and South London.	Liverpool Overhead.	Roundhay, Leeds.	South Staffordshire.
	Third Rail Conductor.		Overhead Electric Conductors.	
Type of engines	Vertical compound non-condensing.	Horizontal compound condensing.	Horizontal single cylinder.	Horizontal coupled compound surface condensing.
Type of boilers	Lancashire	Lancashire	Babcock Wilcox	Lancashire
Coal per I.H.P. per hour and per train or car mile.	About 4 lbs. „ 28 lbs.	2·96 lbs. 17 lbs.	6·5 lbs.* 14 lbs.	..
Type of dynamos.	Edison-Hopkinson	Elwell-Parker, shunt-wound.	Thomson-Houston	Elwell-Parker, shunt wound.
Efficiency of ditto.	96 per cent.	97·7 per cent.	90 per cent.	93 per cent.
Loss on line.	10 per cent.	2 to 3 amperes	10 per cent.	..
Type of motor.	Hopkinson armature, Gramme ring type, 50 horse-power.	Elwell-Parker, series wound, 40 horse-power, armature built on axle.	..	Elwell-Parker, series wound, single gear 4 to 1.
Efficiency of ditto, and of whole line.	About 88%; maximum, 62%; average, 44%.	..	About 85 per cent. ..	80 per cent. ..
Length in single line	6 miles 24 chains	12½ miles, 10 at work	5¼ miles	8 miles
Intervals of service in minutes.	4	5	9	..
Number of cars running per day.	30 (10 trains)	28 (14 trains)	6, and 2 tow cars	12
Weight of single car empty.	Car, 7 tons; locomotive, 10·35 tons; motors and electric gear, 6 tons.	12½ tons (without motor), motor truck complete, 5·35 tons.	About 5 tons	6¾ tons
Passenger Capacity of single car.	36	56	22, and tow cars 44.	40
Number of motors to a car.	Two to each locomotive.	One	Two, each 15 horse-power.	Two
Maximum speed in miles per hour.	25	30	8	9
Average speed in miles per hour.	13	12	7	6
Voltage.	500	500	300	300
System of increasing power at starting, or difference in amperes when starting and running at speed.	Starting current, 150 amperes; Average current, 60 amperes.	At starting, in series, At speed, in parallel.	At starting, double of average.	Resistance put in motor circuit at starting.
Car mileage per year.	441,765	487,078	197,986	298,836
COST. Total working expenses per train or car mile.	16·1*d.*	13·5*d.*§	5·9*d.*†	4·25*d.*
Working expenses per train or car mile, including only generating station, hauling, repairs and maintenance.	7·39*d.*	5·73*d.*§	..	2·12*d.*
Exs. per train or car mile for generating motive power only.	5·56*d.*	3·7*d.*	1·75*d.*‡	1·01*d.*
Proportion of total working expenses to "line" earnings per car mile (neglecting advertisement receipts, rents, and transfer fees).	66·6 per cent.	72·2 per cent.§	..	60 per cent.

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* Normal power of engine is 200 I.H.P., but daily average is only 60 I.H.P.; coal used, Yorkshire slack.

** Owing to excessive grades.

† Wages, drivers average 30*s.* a week for 10 hour days, conductors 25*s.*

§ These figures are based on cost of 4*d.* per train mile running expenses, guaranteed by Electric Actual cost is 3·7*d.*

of Working by Different Systems.

s.

London.		Birmingham Central.				Buda-Pesth.		
e.	Horse.	Electric Battery.	Steam.	Horse.	Cable.	Electric (conduit).	Steam.	Horse.
ntal e er.	..	Horizontal compound.	Horizontal compound surface condensing.	..	High-pressure.	Horizontal compound condensing.	..	..
ck	..	Multitubular	Locomotive	..	Galloway	Water tube	..	..
	..	..	Coke	..	..	.. 7·04 lbs.	.. 20·8 lbs.	..
	..	Elwell-Parker shunt wound.	..	..	..	Siemens and Halske, ring type.	..	..
	..	..	..	..	..	95 per cent.	..	..
	..	..	..	..	..	..	..	..
	2923-horses	Elwell-Parker series wound.	70 locomotives	..	Cable	Horizontal Siemens.	..	..
ent.	..	..	..	..	..	..	..	..
es	18 miles	6 miles	19 miles	2¼ miles	6 miles	14 miles	10·4 miles	28·6
	Various	5	Various	5	3	..	..	..
p, ager.	308	10	52	9	21	60 motor cars, 2 tow cars.	4 locomotives 9 cars, 3 wagons.	..
vith ar.	2 tons	..	Locomotives, 8½ to 12 tons.	1·9 tons	..	max. 6·4 tons, min. 3·14 tons	..	..
	44	48	60	38	44	24 and 16	..	..
pper	..	One	..	..	Two grippers.	Two 8 H P. One 8 H.P.	..	..
	8	8	..	..	..	11¼ in suburbs.	..	..
	7	6	6	6	6	9·4 3·7	..	..
	..	..	..	..	..	300	..	..
	..	Alterations of battery connections.	..	..	..	..	..	..
7,740,984		140,993	1,225,996	647,652	641,161	2,102,720	209,440	5,993,706
8·49*d.*	8·97*d.*‖	16·55*d.*	11·22*d.*	10·12*d.*	6·32*d.*	4·56*d.*¶	9*d.*¶	5·22*d.*¶
	..	11·59*d.*	6·79*d.*	8·06*d.*	4·22*d.*	1·67*d.*¶	6·13*d.*¶	3·41*d.*¶
3·07*d.*		6·72*d.*	4·24*d.*	6·65*d.*	2·43*d.*	·78*d.*¶	2·85*d.*¶	4·38*d.*¶
per cent.	93·3 per cent.‖	102·6 per cent.	71·0 per cent.	94·8 per cent.	50·1 per cent.	41·8 per cent.¶	118·4 per cent.¶	61·8 per cent.¶

ıdes a *very* well paid staff at generating station, owing to no reserve plant.

e introduction of cable traction, which system has been in operation a little over a year. Power plant ıough to work another 3 miles, so now only working about half power.

our wages are low compared to English.

March 5th, 1894.

GEORGE A. GOODWIN, President, in the Chair.

PILE-DRIVING.

By HENRY O'CONNOR.

In a paper on the construction of Blake's Bridge, Reading, read before the Society last Session by Mr. Burrows, and in which work piles were used to carry the foundations of the piers, the author noticed what seemed, to him, a very small duty as being assigned to them, and that some considerable difference of opinion existed as to the amount of the load that could, with safety, be placed upon piles. Some year or so back the author was himself confronted with the vastly differing formulæ given in the various text-books which refer to this subject, and was induced to make numerous tests, the results of which he ventures to place before this Society, and which he trusts may be of some service to some of the Members. Now, according to the different formulæ given, the dead load requisite to force a driven pile further into the ground is calculable, but when the various results obtained show that with a certain pile this amount may vary between 72 tons and 300 tons, and in another case between 81 tons and 1169 tons, it will be clearly seen that some of the formulæ at least are incorrect. A reference to the table at the end of the paper will show the application of the different formulæ. Of these the one which, on first sight, appears to be most simple and most according to the rules usually adopted for calculating accumulated work, is that of Major Sanders, but on further consideration it may be very clearly seen that many other things have to be allowed for before any formula can be said to give anything like correct or satisfactory results, and which require many other factors to be brought into the calculations.

Trautwine, in his Pocket-book, says that Sanders, in his rule, gives no factor of safety. It seems evident to the author that Trautwine had at the moment forgotten the formula for accumulated work, or he would have taken the 8 on the lower side of the line as the factor of safety. As a matter of fact, Major Sanders calculates the force at the moment of impact in the usual manner, and divides that by 8, no doubt because he has found by his practice this would be a safe load for a pile. That so great a difference of opinion should exist between men of such eminence as the compilers of these formulæ undoubtedly are, is most certainly an indication that there are many different circumstances governing the question. Of these, the one which, it would appear to the author, has the most influence, is the question of the different soils through which the pile may be driven. The different strata which may be met with and through which the pile has to pass, do not appear to have been taken into account in any of the formulæ which the author has been able to find. Mr. Morrison's suggestion, that allowance should be made in Rankine's rule for that portion of the pile which is outside the ground altogether, certainly appears to strike at the point, but not to go quite to the root of the matter. That such an allowance should be made is, without doubt, right, and is a point that few, who give the matter even a moment's consideration, will cavil at; but if this be the case when the pile is a short length out of the ground, it would appear to the author that the soil which surrounds that portion of the pile which is in the ground, and which is by far the greater part of the length, should be taken into consideration and its resistance to the bending tendencies of the pile allowed for in the calculation. It is this liability to bend which rapidly reduces in such a large proportion the strength of a column or a pile as it increases in the ratio of its height to its diameter.

A reference may now be made to Fig. 1, which is a diagram showing by the black line the strength of a hollow cast-iron column of 15 inches diameter and 1 inch metal, according to its length, and by the dotted line the strength of a 14 by 14-inch square pine column. By this diagram the great difference in the strength may be readily seen. Now this loss of strength as the height increases is mainly due to the tendency to bend before referred to, and if the column was sufficiently strongly stayed at various positions along its length the strength would be considerably increased, inasmuch as the column would then bear a load of the same amount as if it were only of the height between the parts stayed. The staying properties of each layer or stratum of soil should therefore, it would seem, be taken into consideration when settling any formula for such work, but it may be mentioned that to find out what this is is a very difficult matter, and one which can only be done after repeated experiment. The author will, however, place before the Members a method which he has adopted, and which gives a fairly accurate result. By driving either a trial pile or the first of the series which are to be driven into the ground, and by noting the exact set due to each blow of the falling ram, a fairly proximate estimate of the compressibility of each stratum may be obtained. The author recently had this noted in the case of two 14-inch square pitch pine piles, and diagram Fig. 2 gives the result of these tests. From this diagram many useful and instructive lessons may be gained. The depths of the various strata may be fairly easily determined by the sudden alteration in the distance the pile was driven by the ram. It should be here mentioned that in each case and at every blow a drop of 5 feet was used, so that, as far as the accumulated energy was concerned, it was uniform. Of course the absolute effective blow due to a falling body is lessened as the resistance of the object struck becomes less, and this must be taken into consideration when any calculations are made of the resistance of the ground. Another point which must not be lost sight of is the resistance due to side friction, and this again brings in another difficult problem, and one which is not very easy of solution. To gain some insight into this the author has had some observations taken on the force necessary to withdraw a 14-inch pitch pine pile. Unfortunately there did not happen to be one which required drawing which had been driven in exactly the same strata as were to be found in the spot where the pile which was tested at each blow was driven, but those to be removed were situated some few hundred yards away, and had been driven in the bed of the river Thames for the purpose of forming a stage for the upholding and directing of cylinders for a new pier, and also for the erection and building of girders, &c., for the approach to same. They were driven into the mud, which lay at about 15 feet below the finished top of the pile, and was about 18 feet thick, then through a thin crust of ballast, and then through a sandy silt to the chalk at about 40 feet below the top of the piles. They were originally driven by the pile engine, of which Fig. 3 is a representation, which has a 30 cwt. ram and is driven by steam.

It may be interesting to note the manner in which it is worked. Steam is connected, by means of iron piping with knuckled joints, and finally india-rubber tubing, to the top of the ram, which is of cast iron and hollowed out in the same way as the ordinary pattern cylinder of an engine, but with ports for the inlet of steam, and the exhaust for the same on top, the piston-rod coming through the lower end and resting on the top of the pile. The ports are worked by a long double-ended lever, to each end of which a thin rope is fastened, which allows the apparatus to be worked from ground level. In the case under notice the whole machinery was fixed upon a barge and was towed to and fixed at the different positions as required. On the admission of steam the pressure causes the cylinder to rise, the piston in this case being stationary, until the required height above the top of the pile is reached, when the steam is shut off and at the same time the exhaust port is opened, when the cylinder, which, as before stated, weighs 30 cwt., falls upon the pile and forces it into the ground. A great number of blows can be given with this arrangement in a very short time, and a fairly large amount of steam is required.

But to return to the withdrawing of the piles. These had been driven some twelve or fifteen months and had had the wash of the incoming and outgoing tides to consolidate the ground around, which was also rendered harder owing to the weight of water, which, at high tide, was about 15 feet high above the mud. This, no doubt, had the effect of making it far more difficult to remove the piles. At first it was proposed to withdraw them by means of a barge weighted at one end and with a short jib at the other, over the end of which the ropes and chains were led to the pile, utilising the rise of the river to lift. This was successful in the case of two or three very near the shore, but it was found that it was necessary on one occasion to let go the tackle, as the barge was on the point of sinking. After this experience it was decided to work only at low tide, and to have the barge down upon the mud, lifting at this time by means of a crab on the barge. This worked successfully, but it was found that it took eight men, working on the handles of the crab, pulling with all their power, to start the pile, but after it had moved about a foot it was comparatively easy.

Working out the gain by means of the crab, the author puts the amount of power expended by the men at 40 lb. each. He is aware that the text-books mention only 20 lb. as the force which a man usually expends when working a handle of a crab, but in this case the men were exerting themselves in no ordinary way, and he is therefore convinced the 40 lb. taken above is not much, if anything, above the mark. The amount of power necessary to start the pile, allowing 10 per cent. for friction on the gearing, and allowing for the atmospheric pressure, was equal to 16 tons, and this, after deducting the weight of the pile, shows some 15 tons as the side friction on the pile. As before shown, the resistance of the ground and the side friction would amount to, say, 300 tons when nearly home, and 24 tons when, say, half-way down; therefore, this amount, less the proportionate amount of the side friction according to depth, may be taken as the absolute resistance which the ground at these points would give.

A column of pitch pine, 30 feet long and 14 inches by 14 inches, would carry an ultimate load of, say, 640 tons, and at this limit would exert a side pressure distributed along the length of the pile, if the lower end may be assumed to be fixed, equal to 256 tons. Now the average resistance of the ground may be calculated by taking a certain number of points in the height and calculating the resistance which the ground would exert, and taking the average of these and the area of the side of the pile, and calculating the proportion of that side to the area of the end, a fairly accurate estimate will be obtained of the resistance of the ground to the bending strain of the pile. Of course, if this resistance be greater than the force exerted in a horizontal direction by bending, owing to the load on the pile, to a sufficient degree to be safe, the ground may be considered hard enough to form a thorough stay to the column. In very many cases the author is quite sure that if this were taken into consideration the result would be astonishing, especially when the piles have been driven through soft mud.

Another matter which must not be lost sight of is, that if a column were subjected to a load of sufficient weight it would bend considerably before breaking, and although the weight which is thrown on a pile while being driven home by the ram does not nearly reach this load, yet in many cases it is quite half the ultimate breaking load of the column unstayed. As an instance of this a cast-iron pile, 30 feet long and 15 inches diameter, of 1-inch metal, may be taken. This would break under a load of 664 tons, and the load which would be upon it at the moment of impact, when a 1-ton ram which had fallen 5 feet struck it and gave it a set of one-fifth of an inch—a very ordinary blow—would equal 300 tons, or, say, half the ultimate breaking load. Now, the deflection of such a beam at half the breaking strain is equal to about 2·2 inch, and this would cause a shortening of the pile, during the period of greatest load, of about three-sixteenths of an inch, and this on the removal of the load, which only rests momentarily upon the pile, would not be noticed when the set was being measured. In this way a cause of error is easily accounted for, and it is this fact which renders the usual formula for accumulated work insufficient in the accurate gauging of the load which a pile may carry.

While driving 164 piles in a new retort-house at Beckton recently, considerable difficulty was found in getting the piles to stand the test specified. It may be mentioned that the piles were of cast iron, 15 inches diameter outside, and of 1-inch metal, with a circular point of about 4½ inches diameter, tapering for about 1 foot 3 inches, as shown on Fig. 4. A section of the ground through which they had to be driven is shown on Fig. 5. It was specified "that the piles should be driven into the gravel to such a point of resistance, that the impact due to a ram weighing 1 ton falling from a height of 5 feet will not exceed a quarter of an inch for four blows from such ram. Whilst the piles are being driven a hard wooden dolly must be placed between the ram and the head of the pile to prevent fracture."

A very serious trouble was experienced at the outset, owing to the fact that the piles were driven in several cases through the thin crust of ballast without standing the specified test; the skin friction proved of so little good in sustaining the pile that it went right down to the hard chalk which, as will be seen by Fig. 5, is found at about 75 feet from the surface. A number of different means were employed to prevent this. Shoes of the pattern shown in Fig. 6 were tried with varying success; next a wooden block, 8 inches all ways, was experimented with, and this proved very successful; so much so that this principle has been adopted and the nose of the pile cast square, as seen at Fig. 7.

Another point which had to be decided at the time was as to the meaning of the expression a "hard wooden dolly," no mention having been made in the specification as to whether the wood composing the dolly should have the grain running vertically or horizontally. Comparative tests were made, and this showed that a pile which had a set of three-eighths of an inch, due to the last four 5-feet blows of one ton, when the hard wooden dolly was 2 feet 6 inches long and placed vertically, and fitted into a wrought-iron driving cap, as shown at Fig. 8, had a set of only five-sixteenths of an inch for four blows of the same character when the 16-inch by 16-inch timber was laid with the grain horizontal and fitting over the wrought-iron cap. This set was still further reduced when the 16-inch by 16-inch timber was laid directly on to the pile without the interposition of the wrought-iron driving cap. This was no doubt owing to the surface of iron exposed to the dolly only being about 47 square inches, against 176 square inches when the driving cap was fixed on the pile. A further test was made to observe the effect of a dead load upon a pile which had been tested with the 2 feet 6 inch wooden dolly placed vertically over the iron driving cap, and had had a set of three-eighths of an inch only for the four blows. Wrought-iron joists and steel rails were gradually laid on until 100 tons had been placed, and beyond a set of three-sixteenths of an inch, when 20 tons had been put on the pile, taking its bearing upon the ballast, no further subsidence took place.

It was decided to continue the weighting up to 120 tons, when it was observed that the pile had gone down rather less than one-sixteenth of an inch. This latter weight, therefore, may be taken to be the amount required to drive the pile the same distance as the last blow of the ram as received by the pile with the wooden dolly vertically between. These cast-iron piles were mostly driven by Sisson and White's pile-driving machine, of which Fig. 9 is a representation. In this machine an endless chain is kept continually in motion by a steam engine, the chain being made of flat links, and the ram having a bolt which can be made by means of a lever to work into the chain. This lever is worked from the ground level by means of a rope, but is only used to drive the bolt into the chain. To release the bolt a bent iron staple is affixed at whatever height may be desired, so that it may just miss the ram on rising, but will engage with the lever on its side, and forcing it outwards withdraw the bolt and allow the ram to fall by its own weight and strike the pile. This machine appeared to work well, and a considerable quantity of piles were driven by it at a very rapid speed, as frequently four piles 30 feet long were driven to the test in one day.

A short while back the author read a description of some piles which had recently been driven in America, and was astounded at the enormous drop given to the ram, which was in some cases as much as 50 .feet, and the weight of which varied from 2800 lb. to 3200 and 3800 lb. Taking an average of these, say 3300 lb., and working out the accumulated energy imparted by such a blow, when the set of the pile was 1½ inches, which it is stated was sometimes the case, this would equal an average of over 589 tons. One is not surprised to hear that 8 per cent. of the heads crushed, despite an iron cap, and that the vibration of the blow was easily felt at a distance of some 400 feet. Borings showed from 10 to 20 feet of rubbish recently shot, next blue clay and quicksand down to 60 feet, then rock. 1700 piles were driven at 25½ inches centres, averaging 51 feet long, and were 16 inches square at the butt, tapering down to 11 inches at the other end. The author would observe that from his experience the increase of the blow, due to an increased fall of the ram, is not, in the case of a pile engine, in direct proportion to the height of the fall, this being probably due to the friction on the guides which keep the ram from deviating from the direct line to the head of the pile.

Having made several tests to obtain an average of the extent to which this friction lessened the blow, the author has found that with a pile which was being driven at an even rate into the ground, with a 5 feet drop, when given a blow with the same ram and with a 7 feet 6 inch drop, the loss by friction was equal to some 6¼ per cent., and with a further increase to a 10 feet drop the friction reduced the efficiency of the blow some 11¼ per cent. The author, while he has not been able to propound a new formula for the calculation of the weight which may be safely placed upon piles, which would be correct under all circumstances, has endeavoured to point out some few methods of arriving at what matters should be taken into consideration when any particular calculations for the purpose are about to be made. For his own part he should have no hesitation in placing 40 tons upon a 14 inch square pitch pine pile which had been driven into the soil shown at Fig. 5 to the test which has been previously mentioned as specified for the iron piles, and he has been informed that some time back such a pile was loaded with 80 tons without showing any signs of sinking.

With regard to the cost of pile-driving, as compared with excavating and timbering, a few figures may be of advantage. The cost of a 12 inch diameter iron pile of 1 inch metal, driven to a depth of 30 feet and filled with concrete, would be about 13*l.* 5*s.*, and the cost of a 12 inch by 12 inch pitch pine pile, driven to the same depth, would be about 4*l.* This would have to be compared with the smallest hole that can be satisfactorily excavated, and this may be taken as 6 feet by 5 feet, and would cost, for a depth of 30 feet including timbering, use of timber and concreting, about 31*l.* That the last method of forming foundations mentioned would sustain a much greater load than either of those previously mentioned is easily understood, but there are many cases in which a smaller load has to be carried, and in these cases piles may be advantageously used.

In working out the strength of cast-iron piles, a diagram, shown at Fig. 10, recently got out by the author for finding the safe load which might be placed on cast-iron columns, may be usefully employed. The curve laid down is the result of an enormous number of calculations, which were most carefully checked. The safe load has been taken as one-tenth of the breaking load. The method of using this diagram is as follows: Having decided upon the approximate diameter of the columns and noted the number of diameters in the height, take the line opposite the corresponding number on the left-hand side of the diagram, and follow it until it is crossed by the curved line, and from the point where these two lines cut, proceed vertically downward to find what division of the ultimate crushing load is necessary as a factor of safety. By multiplying this divisor by the weight required to be carried, and dividing this by 49 (the number of tons which will crush a square inch of cast iron), the necessary sectional area in square inches may be obtained.

TABLE SHOWING VARIOUS PILE-DRIVING FORMULÆ.

	Morrison's Rule.	Weisbach's Rule.	Sanders' Rule.	Trautwine's Rule.	Rankine's Rule.
Formulæ	$W\left(\frac{H'-H}{S'-S}\right)$	$\frac{W^2 H}{S(W+P)}$	$\frac{W H}{8 S}$	$\frac{\sqrt[3]{H}\times W\times{\cdot}023}{S+1}$	$\sqrt{\left(\frac{4 E a W H}{L}+\frac{4 E^2 a^2 S^2}{L^2}\right)}-\frac{2\times E a S}{L}$
Statement	$20\left(\frac{6{\cdot}5-5}{{\cdot}023-{\cdot}0183}\right)$	$\frac{400\times 5}{\frac{11}{600}(20+25)}$	$\frac{20\times 60}{8\times{\cdot}22}$	$\frac{1{\cdot}71\times\overset{\text{lbs.}}{2240}\times{\cdot}023}{{\cdot}22''+1}$	$\sqrt{\left(\frac{4\times 8214\times{\cdot}7854\times 1\times 5}{25}+\frac{4\times 8214^2\times{\cdot}7854^2\times\frac{11}{600}^2}{25^2}\right)}$ $-\frac{2\times 8214\times{\cdot}7854\times\frac{11}{600}}{25}$
Weight required to sink pile further in ground.	300 tons	121·2 tons	safe load, 34·2 tons.	72·21 tons	79 tons
Do. do. another pile.	460·8 tons	521·75 tons	safe load, 146·65 tons.	81·75 tons	86·44 tons

In the above—

W = weight of ram.
H = height of fall.
H' = greater height of fall.
S = set of pile due to last blow.
S' = „ „ blow H'.

E = modulus of elasticity.
a = sectional area of pile.
L = length of pile.
P = weight „

DISCUSSION.

The PRESIDENT, after proposing a cordial vote of thanks to Mr. O'Connor for his able and interesting paper, said it did not fall to the lot of every engineer to have the opportunity of making experiments such as had been carried out by Mr. O'Connor, and thanks were due to him for having devoted such a large portion of his time to making and recording them for the benefit of his professional brethren. As to the formula $\frac{WH}{8y}$, there was no doubt that it must be incorrect, because if a pile was being driven with a small ram, so that the penetration became zero, the pile, according to that formula, would carry an infinite load, whereas it was known that if the weight of the ram was much increased, the pile would further penetrate into the soil. He believed that the best proportion for the weight of the ram was, that it should be equal to the weight of the pile that was being driven. A knowledge of the resistance of the different strata did not appear to be very important, because, the set was attained by reason of resistance caused by the strata, and therefore the set must be some function of the resistance, and if a formula brought in the set, it must necessarily bring in the resistance of the soil. If two piles were driven in two dissimilar soils until the same penetration was reached with the same energy in foot-tons or foot-pounds in the falling weight, those two piles would bear the same ultimate load. It was really the set that affected the question, rather than the knowledge of the resistance of any particular strata which were being driven through.

With reference to the side staying power of the soil, it did not appear to be very important that it should be known, for if it was of a yielding nature, so that it could not give much side or lateral support to the pile, in that case it was not wanted, for in a yielding soil the penetration would be large, and consequently the strain on the pile would be reduced. On the other hand, if the soil was hard and the pile was thus subjected to considerable compressive strain, the soil would necessarily give considerable lateral support when required. With regard to the use of a dolly in driving, it had been referred to as having been used in a vertical position; naturally, if it were used so that the fibre was horizontal, there would be more elasticity in it, between the fibres, and the blow would not be so forcible upon the pile, so that the results alluded to by Mr. O'Connor were clearly explained by the fact that in one case they had, as it were, a solid mass when the fibres were practically transmitting the blow to the pile, and in the other case they were lying one on the other, and yielded to compression. The maximum height from which it was useful to let a ram fall was about 40 feet. Above that height there was not much increase of the velocity and of the energy, owing to the resistance of the air and the friction of the side guides. In 1886 Mr. A. C. Hurtzig read before the Liverpool Engineering Society a paper on pile-driving, and, as it contained some valuable information, he desired to call attention to it, and, with the permission of the author, had extracted two diagrams, Figs. 11 and 12, of which Fig. 11 showed graphically the relation between energy of blows, set per blow, and extreme supporting power, of a fir pile; while Fig. 12 gave the curves from which the extreme supporting power of a similar pile, under varying energies of blows and sets, could be arrived at. The formula from which these had been obtained was the first of the four in the following table which had been worked out for different ratios of length in feet to area of pile in square inches, in which

Y = set of last blow in feet.
X = energy of last blow in foot-tons.
P = extreme supporting power of pile in tons.

Formula.	Ratio $\frac{l}{S}$	Corresponding Lengths of Pile for		
		Sectional Area 12 in. × 12 in. = 144 sq. in.	Sectional Area 13 in. × 13 in. = 169 sq. in.	Sectional Area 14 in. × 14 in. = 196 sq. in.
		feet.	feet.	feet.
$Y = \frac{X}{P} - \frac{P}{500}$	$\frac{1}{4}$	36	42	49
$Y = \frac{X}{P} - \frac{P}{625}$	$\frac{1}{5}$	29	34	39
$Y = \frac{X}{P} - \frac{P}{750}$	$\frac{1}{6}$	24	28	33
$Y = \frac{X}{P} - \frac{P}{1000}$	$\frac{1}{8}$	18	21	24

It should be mentioned that the above are obtained from a due and proper consideration of the elastic limit of the material of the pile, amount of compression, the cross section, length, and a constant obtained from some 7000 observations made by McAlpine;

the fundamental equation being $W h = 5\cdot6 \frac{l}{E S} P^2 + P y.$ The author of the two diagrams had tested them in several cases, when they were found to be very accurate. In one instance, calculation from certain data showed that 61,533 lb. would be the supporting power of the pile, and when it was tested it was found to be 62,500 lb. Mr. O'Connor said it would be proper to place 40 tons on a single pile driven under certain circumstances. He (the President) had just worked the weight out from Mr. Hurtzig's diagrams, and found that it gave 47 tons.

The vote of thanks was carried by acclamation.

Mr. Henry Adams said that in any operation involving the expenditure of a large amount of energy, it was of the greatest importance that the energy should be judiciously expended, or there would be more than the usual waste. Pile-driving was especially a case in point. It was theoretically indifferent whether they had a ram of 500 lb. falling 20 feet or a ram of 2000 lb. falling 5 feet. They would give the same energy, but the result in the work would be very different. It was known that a light ram with a long fall shattered the head of a pile, and that a heavy ram with a lower fall caused penetration at the point. That might be illustrated by the difference between the effect of a steam hammer and that of a hydraulic forging-press. The hammer did its work on the surface of the material brought under it, while the forging-press exerted its energy through the whole mass. A similar difference was observed between hydraulic riveting and hand-riveting; hand-riveting did only surface work, but hydraulic riveting always filled the hole first. Perhaps the familiar operation of expanding a piston ring was as good an example as any to illustrate the point. With the sharp light blows of the hammer the inner surface of the piston ring was expanded without affecting the remainder of the metal, and the ring was set out. The opposite state of things was illustrated by the work of a mason who used a heavy hammer, and gave a lunge rather than a blow. That was done in order to get the energy below the surface of the stone, and to split off a mass. In pile-driving they did not want any surface work; they wanted the force to penetrate. He thought that other facts had come out in the paper which showed that they should use a heavy ram with a small fall. The diagram showing the set produced by each blow might be put in another way which would show a little more clearly wha was the result. The method of procedure would be as follows:—Draw to scale the different strata which would be passed through such as made ground, clay, gravel and chalk; then, at an depth, set off from a vertical line the ordinate of the number of blows of uniform energy which had been given to reach that depth. Then, joining the extremities of the ordinates, there would be a line representing the energy expended in reaching the different levels. The angle of the line would vary according to the strata passed through—in fact, the angle of the line would indicate the depth and quality of the strata when they were otherwise unknown.

He was not aware of any good experiments in pile-driving giving a direct comparison between percussion and pressure. By the ordinary view that was taken, if they had a horizontal line—*a b* of the diagram which he had prepared (see Fig. 13)—representing the weight of the ram, and a vertical line *b c* representing the fall, then the rectangle formed by those lines gave the measure of the energy; and *b c*, being continued to *e*, so that *c e* represented the set of the pile, *b f* drawn parallel to *d e* gave *c f* as the usually accepted average resistance to penetration. It was, however, far from being correct as the compression of the pile itself was omitted, and that might easily halve the resulting pressure. If *c e* were continued to *h*, so that *c h* represented the set + the compression, then *c i* would be much nearer the truth as a measure of the resistance. It would be very interesting to get some direct experiment as a test. At the Institution of Civil Engineers, in the previous week, there was read a paper from which he (Mr. Adams) had made up a diagram, Fig. 14, showing that point with regard to lead. The energy of the blows of a steam hammer were represented by vertical rectangles, and the length of the equivalent horizontal rectangles gave the resulting average pressure as usually estimated; but, on the actual pressure being tested with a

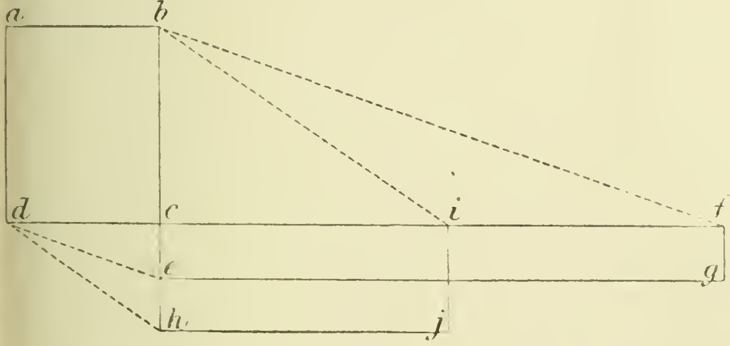


Fig. 13.

hydraulic press, the resistance of the lead block was found to be between a fourth and a fifth of the amount. Lead was rather a bad material for illustration because of its flowing qualities, but it indicated in a striking manner the error that might arise in estimating the supporting power of a body upon calculating from percussion. From the experience which he had had in pile-driving, he agreed that a 1-ton ram with a fall of from 5 feet to 10 feet, and a final set of a quarter of an inch in the last four blows was a very good test for ordinary piles.

Mr. P. Le Neve Foster said he feared he could not say anything new respecting pile-driving after the exhaustive paper which he had listened to with great interest, but having, for the construction of the new lock and weir at Richmond, driven some 800 feet run of half-tide dam, and 500 feet run of dam to keep out the highest tides, he would offer a few remarks. Those dams were constructed with pitch-pine piles, 12 inches and 13 inches square, driven at intervals of 7 feet 6 inches to 8 feet. Horizontal walings, 12 inches by 8 inches, were bolted to those piles, and formed guides for the sheet piles, which were from 12 inches to 15 inches wide, and 4½ inches to 5 inches thick. The main piles were driven from 18 feet to 26 feet into the London clay, which there formed the bed of the river, and the sheet piles from 15 feet to 22 feet, according as they were on the upstream or downstream side of the foundations, which were excavated in the dams to the required depths, and afterwards filled with concrete. The sheet piles formed a casing for holding the concrete, and when the work was completed the piles were cut off to the level of the bottom of the river. In the lock dam, the top of which was above the level of the highest tides, the piles were 20 feet out of the ground, whilst those for the half-tide dams were only 10 feet. The piles were all driven by steam, an ordinary pile engine or derrick 35 feet high being used; the ram, which weighed from 16 to 18 cwt., being raised by a small hoisting engine. They found that a double cylinder hoisting engine, made by the Lidgerwood Manufacturing Company of New York, gave the best results, and on the average drove three piles to two driven by an engine of English make. That engine was provided with a very effective friction drum, which was loose on the shaft on which it had long bearings, and could be thrown into gear by a lever, the arrangement being such that a very slight pressure would hold it against any load that the engine could hoist, whilst it could be released instantly by means of a spiral spring. Much time might be saved when driving short piles by using a rope made fast to a light ram, which could be raised to the required height above the head of the pile, and when the drum was released the weight dropped, overhauling the drum as it fell. In that way the use of the tongs could be avoided and considerable time saved. When a heavy ram and chain were used, tongs were necessary.

He attached a good deal of importance to the form of shoe used. Those made entirely of wrought iron usually had insufficient seating for the end of the pile, whilst some of the shoes with cast-iron points were clumsy and blunt. They used shoes pointed to an angle of 32°. The shoe consisted of a kind of pyramid of cast iron weighing about 14 lb., about 7½ inches in length, which was fastened to the pile by two wrought-iron stages 1¾ inches by $\frac{5}{16}$ inch, passing through holes in the casting, the total weight of a complete shoe being 24 lb. Those shoes gave a seating to the end of the pile of 2 inches square. The sheet piles were shod with a piece of sheet steel, No. 12 wire gauge, about 9 inches long and weighing 2½ lb. That was bent round the point, and fastened to the pile with six 2½-inch clout nails. The piles were bevelled off from the driving point about 3 inches in 9 inches, and the remaining 3 inches was tapered off in 18 inches up the side farthest from the point.

He thought the statement respecting the driving of some piles in America with a drop of 50 feet must be taken with some reserve, and he should be surprised, not at 8 per cent. of the heads being crushed, but that even 8 per cent. were not split to pieces. No timber grown in the United States could have stood such pounding. On the other hand, the best American practice was, he believed, in favour of short and rapid blows with a comparatively heavy ram, and he thought that there could be no question that a long blow with a light ram was far more injurious, damaging not only the heads and splitting the piles, but crushing their points, and thereby preventing them sinking.

Mr. J. W. **Wilson**, jun., said there appeared to be a lack of literature upon the subject of pile-driving machines. Mr Henry Adams, one of their past Presidents, read a paper on "Timber Piling" before the Society of Architects, a few years ago, which fact he omitted to mention when opening the discussion. Another of their past Presidents, Mr. Perry F. Nursey, had also read a paper on "Pile-driving Machines" before the Cleveland Institution of Engineers at Middlesborough in 1886, and he wished the author of the present paper had been able to devote more of his communication to what was a most important subject to engineers. In connection with the drawing of piles, he might refer to the method adopted in removing a coffer dam which had been employed recently in the construction of one of the London bridges over the Thames. When the filling up of the interior of the coffer dam approached ground line a series of screw auger holes was put transversely through the piles a few feet below the surface of the bed of the river; and subsequently, when the piles were no longer needed, they were simply broken off by a violent pull given transversely upon their upper ends. It was said that breaking them off thus was a better plan than drawing them out or sawing them off; and he understood from Mr. Le Neve Foster, that this was the plan he adopted at the Richmond lock and weir works. He was interested to see in the paper a reference to the use of the wooden dolly for the driving of cast-iron piles. He touched upon that point in a paper which he read before the Society in 1875, in which he had pointed out that the late Mr. John Dixon, whose name they all respected, was one of the pioneers of this method of successfully driving cast-iron piles. Mr. Dixon stiffened his piles by casting on four projecting ribs running from end to end. Experiments were made two or three years ago at Portsmouth Dockyard by Major Raban, R.E., in order to obtain a larger base for some iron piles he was driving into the somewhat unsatisfactory soil which the piers there had to be constructed upon; and he conceived the idea that the base of the pile might be extended by pumping up the soil, which was chiefly sand, from below the open end of the circular cast-iron pile; and so excavating a species of chamber of enlarged diameter below the pile; and as quickly as possible filling up this space with liquid cement concrete in order to provide a mushroom head to the pile. Major Raban was not entirely successful in arriving at the desired result, as before the cement could be got down, the sand round the enlarged cavity had a tendency to fall in. He still believed, however, that something of the kind might be done satisfactorily.

The author had not referred to the gunpowder pile-driving machine. That appliance was hardly ever seen now in this country, and as far as he (Mr. Wilson) was able to ascertain, engineers were not agreed as to why it was not more used. It was a simple apparatus. The ram was raised by an explosion of gunpowder or guncotton. The charge was exploded by the rapid increase of temperature due to the compression of the air contained in a cylindrical cavity in the cast-iron cap placed at the head of the pile, into which a projecting piston on the bottom of the ram penetrated at each blow, and at the bottom of which the charge was placed. The idea was that the explosion of the charge should not only throw the ram up again to the top of its stroke ready for another blow, but should also drive the pile into the ground. Although some were sceptical about it, experiments showed that the explosion of the powder would even quadruple the force of the blow. It had been said that after a series of blows the chamber in which the discharge took place became so hot that the charge went off prematurely, but that was a difficulty which might be overcome. He hoped to hear the application of electricity to pile-driving advocated.

With an ordinary steam pile-driver like the Nasmyth, or its successors, they got a necessarily limited stroke to the blow. There were, however, cases in which a longer stroke was required, and then they had to resort to the old chain pile-drivers. Those of course were often driven by the addition of a steam engine and boiler to the pile-frame, in order to actuate the endless chain; he knew, however, of a case in which the contractor had reverted to the old hand crab apparatus because of the trouble involved in moving the steam plant from pile to pile. It seemed to him that it would be a comparatively simple matter to have an endless chain travelling round, as mentioned in the paper, and to raise the ram by the chain in the way to which engineers were accustomed; the revolution of the chain being produced by a small electric motor. This would not practically add anything to the weight of the apparatus, and should be economical where the necessary current was available.

Mr. W. Clark said that in the unavoidable absence of his father who, having had considerable experience in pile-driving and similar work, was invited to be present that evening, he had been asked to read the following remarks:—"Having carefully read the advance copy of Mr. O'Connor's paper on pile-driving, I must say that it is extremely interesting and contains much useful information. The only remark I would venture to make in regard to the important question as to what weight may safely be placed upon a pile is, that it should, I think, have introduced into the calculation the element of rapidity with which the blows given in driving are delivered. It will have been observed that when driving into sand, the first blow may give very little or even no set whatever, and, possibly, but very little in the second, and if these blows are at long intervals (as is the case with hand driving) the pile may very easily be supposed to have reached a satisfactory depth. But if such a machine as Lacour's, shown in Fig. 3, or Sisson & White's, shown at Fig. 9, be set to work upon it, the pile will continue to travel quite easily. With Lacour's machine I have seen a 16 inch square greenheart pile driven 13 feet into good clay in five minutes (accurately timed), but to do this a powerful boiler is necessary. It is very common for piles which are considered to be fairly well driven which, judged by the set resulting from slow driving, leave no question in one's mind but that they will carry their load in safety—I say it is common for these same piles to sink under the vibrations resulting from a steam crane working near them. I must confess that, personally, this question has been too much of guesswork, and I would be very grateful for some reliable formula for safe loads on wood piles. It is always a perplexing question, at times driving them unnecessarily deep into good ground, and, again, where there is no bottom to the mud, being very anxious as to the possible results."

Mr. JOSEPH BERNAYS said he was very much interested in Fig. 5, which showed the section of the ground, as, some years ago, he had to drive piles in precisely the same sort of ground for carrying a heavy chimney. He had to take the upper part away to form a deep concrete foundation until he came to the silty clay into which the piles had to be driven. Piles 12 inches square were driven in about 35 feet, and they had borne a very heavy chimney at a calculated load of about 36 tons on a pile. He did not gather how far the cast-iron piles mentioned in the paper went down into the sand.

Mr. O'CONNOR said they went down to the ballast only.

Mr. BERNAYS said the piles of which he was speaking went through the ballast into the silty sand. He did not quite gather from the paper what Mr. Morrison's suggestion meant. The author said, "Mr. Morrison's suggestion that allowance should be made for that portion of the pile which is outside the ground altogether, certainly appears to strike at the point." He did not understand how that could influence the force or the energy of the blow. It would naturally affect it so far as friction had not to be overcome at that part, but in any other way the question of the length of the pile outside the ground could hardly affect the result of driving, except, possibly, as regards the liability to bending. A great point had been made of the pressure of the ground against the sides of the pile, but the effect of that pressure was only to hold the pile in position. If there was not sufficient resistance on the part of the ground to securely uphold the pile, it was necessary either to secure the pile-head in a concrete bed, or to hold the piles together by a grating or sills to prevent deviation. He once had a peculiar case where a pile was driven about 35 feet deep into silty or soft material, and, as the ultimate set was not sufficiently small, a dolly about 15 feet in length was sent down after it until level with the ground. Then another pile of 25 feet was taken and treated as a second dolly, and when that had been driven 10 feet or 15 feet into the ground, it was found that the three pieces of timber no longer stood in a straight line, and he could get no satisfactory result. Afterwards, much longer piles were used. The slight resistance of the ground was of very great influence in that case. In all pile-driving the question of the nature of the soil was of the very greatest importance. The question presented itself, which was the real resisting portion in a pile? the point, or the sides? In some cases the greater part of the strain was borne by the point of the pile; and in other cases it was very largely taken by the side resistance. How any formula could take notice of these various circumstances, he was at a loss to say. As regards the hard wooden dolly mentioned by the author, he (the speaker) should hardly have thought it worth while to make experiments with the grain running across, as a great part of the blow must be lost in compressing the fibres of the dolly. He quite followed Mr. Adams's paradox when he said that, whilst they really required something which should resist dead pressure in their usual method of pile-driving, what they did was to apply energy to the material. The most natural plan would be to sink a pile by pressure, but the cost of the arrangements, as well as the weight of the machinery, would be too great, and, in some grounds, the machine itself would go down instead.

Mr. T. Gibson said he had to draw some screw moorings from the Albert Dock about two years ago. He found that it took about 40 tons to do it. The barge was hove down to the water's edge by a steam crab winch, and remained in that position for about half an hour before the screw moved. He thought that this showed that although a pile might not settle at once under the dead load at first applied to it, it might settle afterwards. He also tested a pile on the opposite side of the river to those at Beckton. It was 3 feet 6 inches in diameter, with a screw blade 9 inches outside the pile. The test load applied was 74 tons. That pile settled about ¼ inch when 4 feet in the London clay, the core having been taken out to the cutting edge before applying the test load.

Mr. W. Worby Beaumont said that Mr. Wilson had remarked that there was not much literature on pile-driving, but he was sorry to say that that had not been his experience.

He had met with a great deal of literature on the subject. Much of it was of a mathematical order, and much of it was only fit for the waste-paper basket. Great dissimilarity would be found among the formulæ of different writers, and in the various text-books. He believed that he could safely say that very little of the information to be found was of the slightest value except to those who had had a great deal of experience in pile-driving, and to such persons the formulæ were not necessary. With regard to the difference between the use of heavy rams falling through short ranges, and light rams falling through greater ranges, an engineer might very well present the question to his mind by thinking simply of the inertia of rest of the pile on the one hand, and of the ram on the other. An extreme case would be the attempt to move an anvil with a tack-hammer. No matter what length of arm the user of the tack-hammer might have, the anvil would not know much about the blow. On the other hand, a weight similar to that of the anvil, and falling through a very small range of fall, would persuade the anvil beneath that something had happened. The question was really one of the inertia of the two things.

With regard to the side friction, many problems and many difficulties occurred. Almost all the troubles were connected with the question of side friction, especially in strata which varied very much. A case had occurred on the Tyneside, in which there was a bed of chalk in made ground with sand and gravel, and the chalk formed a very effective stop to the progress of the pile, although the bed was of small thickness. At least it was found that the only way to get the piles down was to bore the chalk. After that, they were driven very easily. It might be said that in a general way, the most perfect pile-driver would be some great giant who could use his thumb to push the pile gradually down, and make it act very much in the way that a hydraulic press acted upon the iron that was being forged. A heavy weight moving through a moderate range gave a blow somewhat in the nature of a push, and it also gave a sufficient velocity of impact on the top of the pile to bring into use the elastic recoil of the material of the pile; and thus the effect of a very sudden blow was felt at the point of the pile, although it was not so materially felt on the top of the pile where the heavy ram expended its energy. It had been observed that piles gradually descended into the soil which supported them when in the neighbourhood of cranes which were at work on river banks and similar places. He had not the slighest doubt that that was the fact. He believed that when vibration of a complicated kind was set up, the hold on the piles by the side friction of the soil in which they stood was overcome. He thought that most people would agree with Mr. Wilson in thinking that electricity might be applied to the work of pile-driving, but he did not think that it at present offered any advantages.

Mr. ALFRED W. SZLUMPER said he had recently had experience in pile-driving and pile-drawing at Barnes, where the South-Western Railway Company was widening and reconstructing the bridge over the Thames. The piles were driven from 9 to 14 feet into the London clay by a Lacour steam pile-driver, and that machine gave every satisfaction. For drawing the piles a rapid means was found by using a Thames Conservancy wreck-raiser or "Samson," that was a lighter 70 feet long by 20 feet beam, fitted with powerful winches, actuated by a 12 horse-power winding engine; strong davits projected over the bow, accommodating a 7-inch steel hawser, &c. The operation of drawing the piles was as follows:—A 2-inch iron sling chain was secured to the pile and the steel hawser was made fast to the chain. The winding engine was then set in motion and the pile withdrawn. When in full working order an average of three piles per hour was thus withdrawn, and the power exerted varied from 20 to 50 tons. The price paid to the contractors for drawing the piles was 12*s.* per pile.

Mr. R. J. SHARPE asked whether he was right in assuming that the piles were driven to a depth of 30 feet into the ground.

Mr. O'CONNOR said that that was so in ordinary cases.

Mr. SHARPE said he could endorse what the author said about the enormous drop given to the ram in driving piles in the United States, as in the case of some piles which he had recently seen driven at Chicago for a foundation, the drop given was, he should think, over 40 feet, and the piles appeared to penetrate 6 or 7, and even 8 inches at each blow. He did not ascertain the weight of the ram, as he was merely looking on casually at the work. The idea of the workmen seemed to be to wind the ram up as high as possible and then let it drop. He did not think that the author's estimate of 4*l.* a pile, or his calculation of 31*l.* for the excavation, was enough. He (the speaker) drew some piles in the river Medway at Rochester. The work was done by lashing a barge to the pile similar to the method described by Mr. Szlumper. The piles were drawn by the rise of the tide lifting the barge. Those piles, however, had been only driven for a temporary jetty, and were not more than 15 feet down into the mud.

Mr. O'Connor said that in most of the tests which he had mentioned in the paper the ram used was about equal in weight to the pile. As to the resistance of the soil, it was a fact that any bending or compression which might take place while the pile was being driven at the moment of the impact of the ram did not show itself afterwards when the set was observed, and consequently the weight which was calculated as having come from the pile was not the exact weight which had been really placed upon it. There was a considerable give in a dolly which was used with the grain vertically. Mr. Adams's diagram (Fig. 13) was a graphic method of working out the formula, which was the usual one for a falling weight, $\frac{W H}{S}$. It was a very interesting way of showing the fact that the blow was not so much as was ordinarily calculated for accumulated work.

With regard to Mr. Foster's remarks, he did not now use shoes upon pitch pine piles, but simply tapered the wood to a square nose of about 6 inches by 6 inches. On some occasions the piles had been drawn and they were found not to be very much burred at the point. He agreed that a short fall with a heavy ram was better than a long fall with a light ram. The auger holes which had been mentioned by Mr. Wilson would, he should think, considerably weaken the pile. As to the cast-iron piece, he did not think that more than one, or at the most two of them had broken while being driven, and considerably over 500 of them had been driven in two years. A 7-foot length of cast-iron pile 12 inches in diameter had been used continuously as a dolly to force a 25-foot length of pile into the ground. The same dolly had been used for driving some hundreds of piles, and it showed that cast iron would bear a great number of blows without breaking. The joint was simply a socket and spigot joint with a place for lead or cement to be run in to prevent the cap twisting. The cap was a flat cast-iron one. He had not met with the gunpowder pile-driver, and he fancied that no great number of blows could be given in a short space of time.

With regard to the use of steam, the Sisson and Arnold pile-driver, shown at Fig. 9, was fixed on wheels and moved about on rails. The piles for which it was used were driven principally for the purpose of carrying an overhead railway. The remarks of Mr. Clark were very interesting, and the information they conveyed was of much value. There was no doubt that a large number of rapidly recurring blows was much better than a slower rate where there was anything like a possibly moving load, or where vibration was likely to take place near the spot where the piles were driven. Mr. Bernays's figure of 36 tons per pile came very near his (Mr. O'Connor's) figure of 40 tons. The suggestion of Mr. Morrison, to which reference had been made, was that the letter L which was shown on the under side of the formula in Rankine's rule, should be made L minus the length of the pile out of the ground. In each case it was L square minus the length of the pile outside the ground squared; and in the last case it was L minus the length of the pile outside the ground.

He was very pleased to hear the remarks about the bending of the piles when three lengths were used. It only went to support the contention in the paper that in driving a pile the tendency to bend should be taken into consideration and allowed for, if the ground was not sufficient to steady the pile. It seemed to him quite true that no formula which would be suitable in every case could be made out. Practice was the only way of obtaining a real knowledge of what a pile could be said to bear in a certain ground. It was practically impossible to calculate by means of a formula the weight which a pile would bear in ground of which the strata were not known. In the case of a screw pile the resistance which it offered upon being drawn was really the resistance due to the weight of the earth upon the screw. The drawing up of a screw pile was, to all intents and purposes, the drawing up of a flat surface with the weight of the ground upon it. He quite agreed with Mr. Beaumont that chalk was a very good resister. Mr. Beaumont's remarks bore out Mr. Clark's as to the sinking of piles which had been driven in sand causing vibration.

As to the application of electricity to pile-driving, one difficulty was that electricity would require some means for generating it. Unless water power was at hand, the usual method was to employ steam, and there did not seem to be any advantage in using electricity when there was a considerable loss of power between the steam engine and the motor, and between the motor and the work required to be done. Therefore he thought that the better plan was to use the steam direct, and make the piston of the cylinder the pile-driver; or to use the steam to drive an endless chain which could be used for lifting the ram; or, again, to use an arrangement with a drum and a winch driven by steam. Mr. Szlumper said he had tried a wreck-raiser for drawing piles. He (Mr. O'Connor) might mention that it was proposed to use one of the Thames Conservancy wreck-raisers for removing the remainder of the piles referred to in the paper. The barge used in the first instance was distinctly too small for the work, and therefore it began to sink. He was glad to hear from Mr. Szlumper the price for drawing piles, namely 12*s.* each ; but he thought that if there were many to be drawn the price would be very remunerative. With regard to Mr. Sharpe's remarks as to the height of the fall, one difficulty which he (the speaker) had found in connection with the use of a short fall was with the men, who when paid by piecework, were able to drive the piles more quickly into the ground by means of a long fall, and consequently to earn more money than they would if they were restricted to a short fall.

Fig. 1

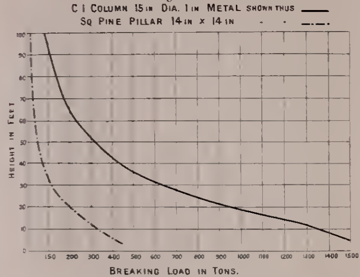


Fig. 2.

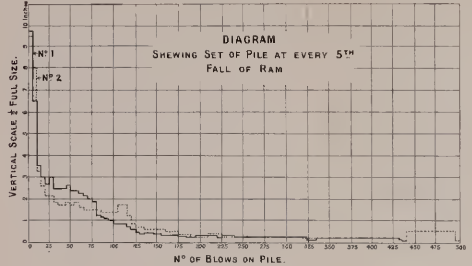


Fig. 3.

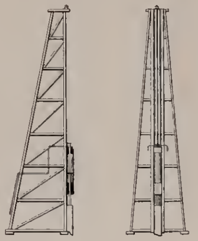
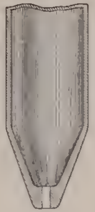


Fig. 4.



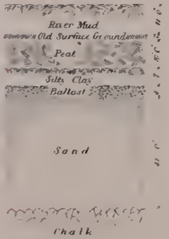
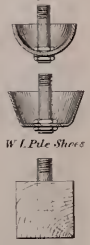


Fig 5.

Fig 6.



W I Pile Shoes

Oak Pile Shoe

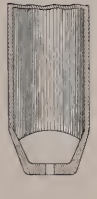


Fig 7.

W I Pile Protector

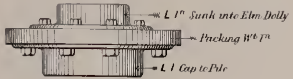


Fig. 8.

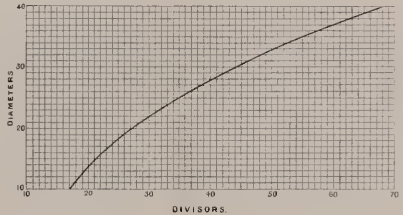


Fig. 10

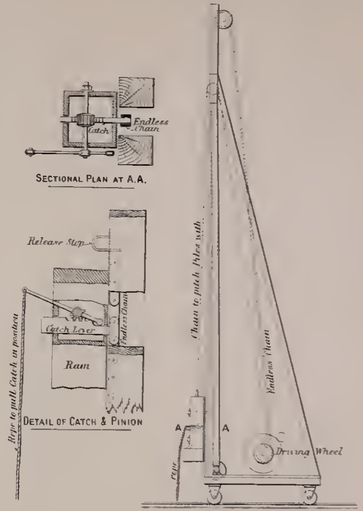
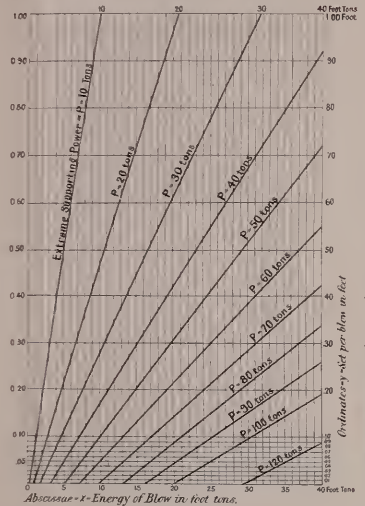


Fig 9.

Fig. 11.

Diagram shewing relation between Energy of blow Set per blow, and Extreme supporting power of a fir pile

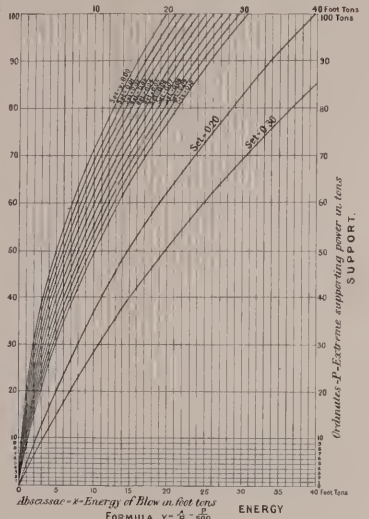


Abscissae = x = Energy of Blow in foot tons.

FORMULA $Y = \frac{x}{P} - \frac{P}{500}$

Fig. 12.

Curves of extreme supporting powers of a fir pile under varying Energy of blow for different Values of Set



Abscissae = x = Energy of Blow in foot tons

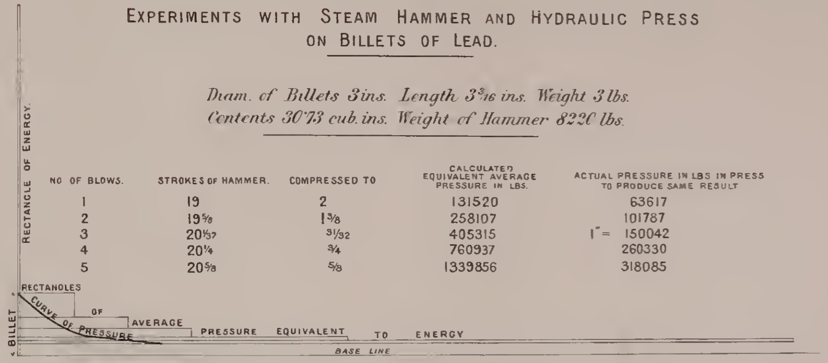
FORMULA $Y = \frac{x}{P} - \frac{P}{500}$

Fig. 14.

EXPERIMENTS WITH STEAM HAMMER AND HYDRAULIC PRESS ON BILLETS OF LEAD.

Diam. of Billets 3 ins. Length $3\frac{3}{16}$ ins. Weight 3 lbs.
Contents 30·73 cub. ins. Weight of Hammer 8220 lbs.

NO OF BLOWS.	STROKES OF HAMMER.	COMPRESSED TO	CALCULATED EQUIVALENT AVERAGE PRESSURE IN LBS.	ACTUAL PRESSURE IN LBS IN PRESS TO PRODUCE SAME RESULT
1	19	2	131520	63617
2	19⅝	1⅜	258107	101787
3	20¹⁄₃₂	³¹⁄₃₂	405315	1" = 150042
4	20¼	¾	760937	260330
5	20⅝	⅝	1339856	318085



E. & F. N. Spon, London & New York.

April 2nd, 1894.

GEORGE A. GOODWIN, President, in the Chair.

GASHOLDER CONSTRUCTION.

By Edward Lloyd Pease.

Gasholder construction is far from being an exact science. It seems still to be in an experimental stage: there are no standard lines or data to be carefully adhered to as in the construction of roofs and bridges. These latter are built to suit the purpose for which they are required, with sufficient strength, and without waste of material. Can this be said of the large gasholders of the present day? Judging by the diversity of design displayed this must be answered in the negative.

In a search for economy in gasholder construction, the first and largest item that catches the attention is that of exterior support; its cost is generally from 30 to 50 per cent. of the total expenditure, without contributing a single foot to the storage capacity on the works. Let us look for a moment at the nature of the support supplied to keep the floating vessel of a gasholder in a level position. When a gasholder was the simple thing as at the beginning of this century, it mattered little if the few short posts used were much more substantial than necessary. It is a very different matter in the case of a modern gasholder, containing as many thousands as the former did hundreds of cubic feet. When a vessel of great size, rising to a height of 150 or 200 feet, has to be surrounded with twenty or thirty columns of a similar height, the question as to what constitutes a safe and economical support is a matter of great importance, and on this point there is great diversity of opinion. Marked contrasts in design are frequently met with in holders of about the same size. The following are examples:—

	Tons.
No. 1 Holder—	
3 lifts, 150′ 0″ × 30′ 0″, weight of columns	553
„ of girders	159
Total	712
No. 2 Holder—	
3 lifts, 150′ 0″ × 30′ 6″, weight of columns	198
„ of girders	66
Total	264
No. 3 Holder—	
3 lifts, 150′ 0″ × 30′ 0″, weight of wrought-iron standards and girders	128

This contrast forces upon the mind the observation that if the last-mentioned design is safe, the former designs are wasteful. From want of evidence to the contrary, it must be taken that the light lattice standards are strong enough. From the fact that very light standards are seen to successfully do the work required of them round a large gasholder, the question arises whether the higher portions of them are of any value at all, or are ever called upon to bear an appreciable strain? And also, whether the inflated cylinder of iron that they enclose, held rigidly by the lower portions of the standards, and incapable of the slightest bending or vibration, is not infinitely stiffer than the higher portions of the standards, and in reality (from its own inherent strength) as immovable as a rock, when the lower portions of the standards are of sufficient strength?

There are other details, however, that have some importance. Many large holders that have worked with great regularity for a long period have crown carriages of the very simplest design and, as compared with some modern carriages, of the very lightest description. There is a fashion in these things, and at the risk of hazarding a suggestion that may be questioned it would almost appear that the use of tangential and radial rollers in carriages on the upper lifts has spread from their use in the large holders of the South Metropolitan Gas Company. If they are necessary, or their use justified on such exceptionally large holders, which in themselves struck out a new line, can they be considered necessary in holders not half the size, when past experience has abundantly shown that very simple and almost fragile carriages are sufficient? If they are not necessary, their use is a mistake, seeing that they are, in proportion to their weight, by far the most costly part of a gasholder. The use of tangential rollers on the outer lift, when one or more lifts rise above the columns, is quite another matter, since the question of leverage of the wind presents itself.

These two points, the massiveness of the exterior supports and the construction of the carriages that bear upon them, with the number and strength of the vertical stays in the holder body (and, perhaps, there ought to be added the weight of the top curb), are all points in which there is great divergence in practice. There is no finality in the existing information on these points. It is just possible that some surprising facts would come to light, if a careful investigation were carried out as to what is proved to be actually sufficient in various existing holders in the four points just referred to. The collection of designs thus formed, if selected in parts and placed together to form one holder, might lead to a standard design —light, simple and cheap. This paper, however, attempts to approach the question of how far the construction of a holder can be cheapened and simplified from other considerations.

The Use of Columns.

It goes almost without saying that the usual custom of providing columns to the full height of the holder is founded on the belief that the holder when fully inflated is not in itself sufficiently strong to resist the force of the wind. Possibly this has to some extent been led up to by the fact that holders have invariably been contained in excavated tanks and counterbalanced, in which case columns have to be provided to support the counterbalance. If it had not been so, and iron tanks on the surface had been used, it would very early have been found that the supporting arrangement of three ropes connected to one weight, even if the ropes were attached to the bottom curb, supplied all the support required, and that the holder itself was abundantly strong and stiff without assistance from any columns. Fig. 1 represents a gasholder supported by three chains attached to the top of the gasholder at equidistant points. The author also exhibits a model showing the same holder supported by three ropes attached at equidistant points to the bottom curb of the holder instead of the top. In this case brick piers are not required, the necessary fall of the weight being secured by the tank being of iron and above the ground.

If, then, the problem of gasholder building had developed from the premisses that small holders were sufficiently strong, instead of from premisses that columns, whilst carrying the balance weights, were also necessary for the support of the holder, there would not now be the very strong prejudice in favour of columns the full height of the holder that is so widely spread. Seeing that the largest gasholder ever constructed has two lifts without external guide framing, and many smaller holders have been built without columns of any description, the fact that guide framing is, to some extent, superfluous, has been demonstrated without doubt. But this fact is not generally acknowledged and acted up to so as to have become trite and uninteresting.

In the opinion commonly prevailing, the function of columns divides itself into two—that of preventing distortion, and of preventing overturning. If they are not needed for the former case they need only be built to meet the second demand upon them—that is to say, if a gasholder will keep its form, columns are only required to such a height as would prevent overturning. There are three factors that lend weight to the theory that the gasholder requires little, if any, exterior support. In the first place, the weight of the sides suspended from the top curb places the side sheeting in tension, and this is at its maximum at the top, and runs out to nothing at the bottom curb. At the bottom of the second lift, in a three-lift gasholder for example, it exists to the extent induced by the weight of the outer lift. In the second place, gasholders are by no means structurally devoid of power to resist the pressure of the wind, for it must be remembered that they are more than able, as far as each of the lifts is concerned, to bear their own weight without distortion, as is shown by the fact of their standing on the tank resting stones before inflation. This structural strength may certainly be estimated as being in reserve, for when inflated and suspended in a normal condition, their powers in this direction are quite untaxed. In the third place, inflation itself creates considerable additional stability in the holder.

In considering the question of the ability of the free lifts or lift of a telescopic holder to withstand wind-pressure without distortion, the strength imparted by all three factors has to be estimated. In a case in which exterior support is discarded altogether, the tension in the sides induced by the hanging weight ceases to be a valuable factor, seeing that it practically does not exist where the light sheeting begins just above the bottom curb, and which is presumably where buckling would first of all show itself, because (if the expression may be allowed) it is not in this position pulling at anything, and therefore not taut. In the following remarks an attempt is made to estimate the ability of a three-lift gasholder, 180 feet diameter by 30 feet deep, to resist the pressure of the wind when

1*st*.—Supplied with outside support to the height of one lift;

2*nd*.—Without any exterior support.

The wind pressure of a 40 lb. per square foot gale against the windward surface of the two upper lifts may be taken to be—

$$\frac{180 \times 60 \times 40}{2} = \text{say, } 97 \text{ tons.}$$

The question of parallelism of the holder need not come into question here, it is presumably secured by the weight and strength of that portion of the holder within the columns working of necessity with a horizontal movement. Whether other means besides the use of ordinary rollers and carriages can be with advantage adopted will be referred to later in this paper.

The outer lift of a 180-foot holder may be taken to weigh about 90 tons. This is supported by the inner and second lifts. The lower part of the second lift, that rising just above the columns, is in vertical tension to the extent of 90 tons—i. e. to the amount of the weight of the outer lift hanging upon it. The outer lift is essentially horizontal. Owing to its position within the columns, and its weight being distributed round the entire circle of the inner lift, there is obviously a strong tendency for the sides to maintain a vertical position, and for the crown of the holder to be horizontal and parallel with the outer lift. Fig. 2 illustrates this point. It represents a three-lift holder 180 feet by 30 feet each lift. The two inner lifts, as shown by a model, are constructed of silk only, without any vertical stiffeners; the outer lift is made of tin of such a weight as to give approximately the same water-pressure as the outer lift of such a holder—viz. 2½ inches. Any stiffness displayed by the two inner lifts is entirely due to the fact that they form the connecting link between the horizontal hanging weight of the outer lift and the vertical support of the gas. The holder can only be bent or distorted about the bottom part of its second lift by a force sufficient to overcome the vertical tendency of the gas and bend it about the same point, the lower third of the gas being unaffected. There is an elasticity and springiness in a column of gas confined under these conditions, when the lower portion is confined in a heavy and horizontal vessel, sufficient to transform by inflation the most flimsy material nto a substantial structure. It may be argued, therefore, that there is considerable stability given to the free lifts of a holder by the column of gas they contain: Being vertical in itself, and held, as it were, as to a third of its height in a vertical position, it supports the vessel by which it is confined.

It is now necessary to consider the strength that the shell of a holder may possess as an iron structure in forming an estimate of the ability of the lifts rising above the guide framing to resist the force of the wind. It has been mentioned hat a holder whilst at rest, and standing on the resting stones n the tank, exhibits no signs of distortion in those portions of he sides that join on to the strong plates of the cup, and that upport approximately the whole of the crushing weight of the ides. It is evident from this that the sides of the holder have t least this amount of structural strength, a strength that is not drawn upon when the holder is inflated and hanging uspended, in contradistinction to standing on the resting tones. The second lift of the holder taken as an example weighs about 80 tons. As the ability to withstand a crushing force equal to this weight still exists when the holder is inflated it must be taken into consideration when estimating the ability of the holder to offer resistance to the distorting power of the wind. Although this second lift is a structure capable of sustaining a weight of 80 tons, the actual conditions under which it exists in normal circumstances are such that in place of being subjected to compression it is really in tension to about the same amount, owing to its own suspension and the weight of the outer holder (90 tons) hanging upon it. The lowest portion of the light sheeting of the second lift, consisting of $\frac{3}{16}$-inch sheets, may be considered to be the first point at which buckling or crumpling would make its appearance. This, however, cannot take place until the vertical tension of 90 tons and the latent strength of the sides of 80 tons, has been overcome—together, equal to 170 tons.

Reference to Fig. 3 will show that the wind pressure of 40 lb. per square foot gale on the inner and second lifts i taken to be 48 tons and 49 tons respectively. That of th inner lift is taken to be applied at the dip of the second lift owing to the holder being a jointed structure. The two force combined produce at the distance shown of 91 feet 6 inches a induced strain of 24 tons, acting downwards as shown by th right-hand arrow. Against this 24 tons is to be placed one half of the 170 tons of the combined resistances—i. e. 85 ton against 24. The conclusion pointed to by these figures is tha whilst buckling tendency on the lee side of the holder may b taken at 24 tons, the force tending to keep them straight an vertical owing to the tension induced by the outer lift is a much as 45 tons—that is, half the weight of the suspende outer lift. Thus, the first of the two factors is in itself mor than sufficient to resist the power of the wind, the structur strength of the holder remaining in reserve.

Besides these two there is a third factor—viz. the strengt imparted to the whole structure by the rigidity of the sheetin when inflated. The sides of a gasholder are, as is well know constructed with strong vertical stays, frequently of chann iron, connecting the plates at the top and at the bottom each lift used in the construction of cups and dips or top a bottom curbs. The sheeting, which is placed on the outside, frequently not attached to the stays. In an uninflated co dition the sheeting adds little to the strength of the shell, b the reverse appears to be the case when gas at considerab pressure is confined within. For the lee side of a gasholder assume a convex form (in elevation) the formation of corrug tions in the side sheeting is essential—that is to say, the ir necessary for the bulging or leaning over of the lee side can only be obtained by a flattening of the sides of the holder.

Reference to Fig. 4 will perhaps elucidate the point. If the top part of the second lift be considered to be forced over to the right by the great power of the wind, the sheeting would be found to be drawn into corrugations as suggested in the sketch. The vertical stays on the lee side are greatly supported by the sheeting. The stays are attached at the top to the strong plates of the dip, to which the sheeting is also attached. In order to depart from the vertical, the stays through the heavy plating must drag upon a large area of sheeting. The sheeting on both sides of the holder, in order to admit of this movement, must, leaving its semicircular form, become flattened and assume that of chords of arcs. This is prevented by the verticals, and also by the support given by the gas. Whilst the former provides that no vertical contraction in the sides takes place, or any flattening in their immediate neighbourhood, it is the gas pressure within that renders the whole rigid, and so struts out the sides that they form a very efficient backstay to the leeside verticals. The centre post and back legs of a derrick crane seem to be to some extent a parallel. The strength of the inflated side sheeting together with the two factors dealt with previously, appear to make up a very effective trio, interacting one with the other.

Holders without Exterior Framing.

No tension exists in the lower portion of the side of the outer lift of a holder, so that this cannot be relied upon, as in the case when the second lift was being considered. In the case of the outer lift, the ability to withstand the wind strain depends on the structural strength of the lift, and the rigidity imparted to it by the inflated sheeting.

Upon examining Fig. 5 it will be seen that the wind-pressure is taken to be 97 tons at 30 feet from the ground, and 50 tons at 15 feet, and the induced compression at X as 40 tons. In a gasholder of ordinary construction of this size, there would be about 40 vertical stays of 6 by 3 by ½ inch channel iron; each may be estimated to be capable of resisting a vertical compression of 19 tons. Taking the 20 verticals on the lee side as effective at X, there is a total effective resistance of 380 tons. As suggested in the foregoing remarks, the side sheeting ties back the verticals, and prevents them bending about the bottom curb to which they are fixed, and in this position they have the very great vertical resistance just mentioned. The factor of safety of nine to one, shown by these figures (40–380 tons), leaves a margin for reduction on the score of too high an estimate of the efficiency of the channel iron verticals. There is absolute proof that the outer lift being able to sustain its own weight of 90 tons, is at least able to sustain a crushing force of 45 tons on the lee side, which in itself is 5 tons more than the estimated induced compression of the wind. There is, therefore, a sufficiency of strength by relying only on that absolutely shown to exist, and without the support of any estimate, however sound. Unless these arguments are altogether fallacious, there is a large margin of strength in an ordinarily constructed 180 feet diameter holder to withstand a gale of wind, without calling upon outside assistance to prevent distortion.

THE EMPLOYMENT OF STEEL ROPES.

There is no doubt whatever but that a well-designed gasholder needs no exterior aids to enable it to withstand the force of the wind, except that which is necessary to keep it in its working position. The vertical rise and fall has been usually secured by the use of columns. This is a very expensive method, the cost of these in lofty holders being a large percentage of the total cost. By doing without columns or wrought-iron standards and arranging that the wind strain on the upper portion of the holder shall be transmitted through the holder itself to the ground line, a great saving in cost must obviously be effected How this is secured by means of steel ropes will now be briefly described.

Fig. 6 shows in outline a single lift gasholder in section with one rope passing over the crown. It must be noticed that three is the smallest number of ropes that suffices to produce parallel movement in a holder. One rope, as shown, checks irregular movement in one direction only. It will be seen that the rope is fixed to a bracket A on the tank, passes over pulleys B and C on the crown, under D on the bottom of the holder, and up to E on the tank where it is fixed; the rope is not fixed, to the holder, the holder is perfectly free to move within the rope. If the holder be regarded as gradually sinking, it will be clear that since D C and C B are fixed distances, D E and A B are the only variable distances, and that it is impossible for D E to increase to a greater amount than A B diminishes, The result of a gale of wind, as suggested by the arrow, is a tendency for both E D and A B to increase at the same time; as this is an impossibility, the holder will remain upright as long as the rope holds. If the circumference of the holder be divided into three equal portions by three ropes trained as this one is, it is impossible for the holder under any circumstances to rise or fall irregularly.

The author exhibits a model of a holder working with two ropes. The arrangement is similar to that shown in Fig. 6, but with the rope duplicated, the second rope being trained the reverse way to the first across the holder. This simple arrangement—viz. that of rope control—has been used with the greatest success in numerous instances, the number of ropes used varying according to the size of the holder. In many cases it has been used when it has been desired to add to the number of lifts in a holder without increasing the height of the columns or standards. A great saving in cost is the result from the adoption of this plan.

Fig. 7 illustrates the threading of a rope on a two-lift gasholder. It may here be stated that there are very many ways of applying the rope system, the details of which are unimportant at the moment. The rope shown is fixed to a bracket at A, passes over B and C, under D on the inner lift, over E on the dip of the outer lift, under F on the bottom curb, and up to G where it is fixed. Whilst the holder descends, and until the outer lift lodges in the tank, the only two variable distances are F G and A B, and since the former can increase only to the extent that the latter, A B, diminishes, the holder cannot tilt over in the direction of G. As soon as the inner lift sinks within the outer, D E and A B are the varying distances, and there is the same inability as before on the part of D E to increase to a greater extent than rope is set at liberty by the approach together of A B. As in the former case, three ropes will theoretically suffice to keep the holder vertical, though in practice more are employed in proportion to the size of the holder, and the amount of wind-pressure to be resisted.

In using four ropes on a two-lift holder as outlined in Fig. 7, the function of the ropes is to equalise the balance between the two sides of the holder, the lee and windward sides. The balance, on being disturbed by the wind, is at once readjusted by the rope on the lee side, it carries some of the overplus of weight, and transfers it to the windward, where weight is required to counterbalance the upheaving of the wind. As an interesting point only, and not because it has any value in actual practice, it is proposed to shortly examine the supporting power of a single rope. In the first place, the training of the rope enables it to do duty up to double its strength. An examination of Fig. 8 will probably make this clear. The training of the rope is precisely the same as that already shown, with the modification that the ends are attached to weights in place of brackets. A point is indicated in the interior of the holder as that about which movement would take place. On the left side is a downward force of 36 tons, this is exactly balanced by the two hanging weights of 18 tons each; therefore, although the work done in supporting the holder is 36 tons, the strain on the rope is but 18 tons.

Applying this to an actual holder, as shown in Fig. 9, it will be found that the 180 feet by 90 feet holder that has been taken as an example requires, under the pressure of a 40 lb. per square foot gale, support to the amount of 36 tons. It would require, therefore, a holder of this great size to strain nearly to breaking point one ordinary $\frac{7}{8}$-inch steel rope. This is merely given as an illustration of the power available in steel ropes in supplying the necessary support to large holders. In actual practice such a holder would be supported by, say, eighteen $\frac{3}{4}$-inch ropes. Contraction and expansion of the rope is arranged for by the use of compression springs placed on the holding brackets to which the ends of the rope are attached.

These details in connection with the rope system may appear somewhat out of place in a paper that commenced with a criticism of the cost of modern holders, but perhaps they may claim admittance on the ground that the support of the holder is a very large item in the cost, and that the economy of using new means, or the wastefulness of the old, cannot be estimated until the new method has substantiated its claims.

DISCUSSION.

The President said it was his pleasurable duty to ask the meeting to accord their thanks to the author for his very interesting paper. He had been particularly struck by the figures which the author had brought out with regard to the value of the supporting material compared to that of the structure itself. He did not know any other structure in which there was such a great disproportion between what he might call the useful portion of the structure and that part which was simply employed to support it. It seemed to him that there was considerable room for improvement in the arrangement of the staging round the holder, in the direction of reducing it. If the author's arguments were soundly based the arrangement which he had brought before the meeting ought to grow in favour very rapidly. With regard to the question of distortion, he did not clearly understand the author, when he referred to the wind-pressure deflecting the sides of the holder. Although the side sheeting might be in considerable tension, it still did not require very much side pressure to distort it out of the vertical line. He did not think that that point had been clearly explained. The author should also be thanked for introducing models, as they rendered the paper very much clearer and more easy to understand that it would have been with diagrams only. The silk model was very interesting. It showed indications of the corrugations which the author had spoken of. As to the rope as used, it would of course, do double duty, because it simply took a turn or bight round a pulley, so bringing two sections into play. He did not quite agree with the author's remark that the rope did double the work which the rope had the power of giving out. It was simply that it was doubled, and therefore each rope took its own strain and double the resisting power was obtained.

The vote of thanks was carried unanimously.

Mr. C. Gandon said he was afraid he could not add anything that was very practical to the discussion, for he had had no experience of gasholders without framing. It appeared to him that in times gone by there was an exaggerated idea as to the strain which the supporting frame of a gasholder had to resist. Engineers had, no doubt, gone to extremes. Mr. George Livesey was the first to somewhat alter the ideas of gas engineers with regard to the question of framing. A gasholder with exceedingly light framing was constructed at the Old Kent Road works, and he (Mr. Gandon) believed that the gasholder led to the idea of gasholders rising without any framing being carried out. He was rather a believer in the scheme which had been described. It seemed to him to be perfectly right in theory, but he did not think he was quite sufficiently convinced of it to carry it out in practice. There was no doubt that in the case of a gasholder which had two portions telescoping into a third portion, the weight of the two outer lifts was sufficient to keep the upper lift in equilibrium and to prevent any tendency of tilting. Mr. Cripps, in a very valuable and clear work, had proved that to be the case, and had shown that the weight of the two outer lifts was considerably in excess of any tilting strain that could be put upon the inner or top lift by the force of the wind, or by snow, or by both combined. There had been several illustrations of that. The first one which he had seen was in the case of a lift at the Rotherhithe Gas-works. That holder had been at work for several years without any mishap. That appeared to be sufficient to prove that the theory was correct; but the great illustration of the theory was the gasholder at East Greenwich, referred to by the author of the paper, and which was the largest gasholder in the world. That structure had six lifts, and the two upper ones ascended without any support, and worked perfectly satisfactorily. Mr. Cripps also showed in his work that in the case of a two-lift gasholder, the weight of the lower lift was quite sufficient to balance the two upper ones under similar conditions, but not with so large a margin of safety. He should not hesitate to have the inner lift of a three-lift holder without framing, if there was anything to largely compensate for doing so. It was true, as the author had said, that the outer framing of a holder was a very expensive item, but it had also occurred to him (Mr. Gandon) that if they were to dispense with the framing they must strengthen the holder proper in order to afford sufficient rigidity. There certainly appeared to be a tendency to buckling when a holder was exposed to a strain such as it would have when there was no framing. Even the silk model on the table seemed to show that. He understood the author to advocate a still further step in advance, by entirely dispensing with the guide framing whether it was a one-lift, a two-lift, or a three-lift holder. He was not prepared to advance any argument against such an arrangement except that engineers had been used to guide framing, which was undoubtedly an additional safeguard against tilting. If a single-lift holder did not have any framing to guide it as it rose, the bottom curb or the bottom of the holder must be held very tightly. The whole strain was thrown upon the bottom of the holder, whereas if they had columns a portion of the strain was thrown upon the guide framing. If the strain was taken by the ingenious device of wire ropes, or by the spiral guides which was another device, the whole strain was thrown upon the bottom curb, and there seemed to be some additional strength needed in the holder to resist it.

The figures given in the paper as to the weights of the framing in different gasholders were rather striking, the weight of the frame being in one case 712 tons, and in another case only 128 tons. He thought, however, that the author would admit that that was not quite a fair comparison, because as he (Mr. Gandon) understood, the 712 tons represented the weight of cast-iron columns, and probably cast-iron girders, whereas in the other case the framing consisted of wrought-iron standards, which, if of latticework, were liable to be attacked with rust and to decay. Cast-iron columns would last practically for ever. He was not advocating cast-iron columns in all cases, for with a holder of 150 to 200 feet in height, it was next to impossible to have cast-iron columns sufficiently rigid to resist a strain at that height. The author referred to tangential rollers, and remarked that they had been practically introduced in the gasholders erected by the South Metropolitan Company. He had seen them on the Continent many years before he saw them in England, and they had always struck him as being very useful. Whether they were necessary or not was another point. But certainly if there was wind pressure in any direction, the tangential rollers would distribute it over the framing more evenly than radial rollers would do. He understood that the author did not admit that fact except by arguing that they were unnecessary for the upper lift ; but if the upper lifts could be sent up without any guidance whatever, then, of course, tangential rollers would be unnecessary. If Mr. Cripps were present at the meeting he would be able to give some very valuable information on this point. He believed to a great extent in these innovations, but he had not sufficient faith in them to be disposed to adopt them beyond the inner lift of a three-lift gasholder. He knew that there were certain gasholders erected without any guide framing, and he believed they had been so far successful and no accident had happened to them. There seemed to be no fear if they were properly constructed.

With regard to framing, he remembered seeing some years ago in London an old gasholder which had a framing of circular wrought-iron columns round it, and that structure was found so dangerously weak, that the framing had to be strengthened by horizontal girders or diagonal ties. He believed that the holder was still in existence in one of the London Gas-works. He was not sure whether it was at Nine Elms or not. As far as he remembered it was a two-lift holder.

Mr. J. W. Wilson, jun., said that he quite went with Mr. Gandon with regard to the statement that wrought-iron built-up standards were open to the objection that the joints might be attacked with rust, but then it was also his (Mr. Wilson's) impression that there was a great deal of difference in the cost of painting the two different kinds. He would ask Mr. Gandon whether it was not the fact that the cost of repainting the elaborate wrought-iron standards from time to time was very much greater in proportion than the cost of painting cast iron.

Mr. Gandon said that undoubtedly it was the case. The cost of painting the lattice girders and stopping the rust from getting between the joints was very heavy.

Mr. Henry O'Connor said he had taken particular interest in the subject of the paper, for when he was in India some four or five years back the same idea occurred to him as had occurred to Mr. Pease, and he took out provisional protection some few months after Mr. Pease had done so for an exactly similar arrangement. There was no question that a gasholder could be guided from the base either by ropes or by some other means, but, as Mr. Gandon had put it, was it worth while to make the bell of the holder, which had to move up and down, heavier in order that it might withstand the strain which would be put upon it by wind and snow, rather than to use a guide framing which was separate, and which did not require to be moved up and down by means of exhausters and so on? Mr. Pease had pointed out, and shown to a certain extent by a model, that the strain on the side sheets was practically taken up by the natural power of the material when the pressure of gas was in the holder. If that were the case, why should not the sides of the holders be made sufficiently light that they would be like the model made of silk, but still able to resist the strain without the channel irons which were generally used to keep holders in an upright position? Then Mr. Gandon had pointed out that in some holders, even with the vertical stiffeners, the framing was not sufficiently strong to withstand the side pressure. As to tangential rollers, the author had mentioned that they had been only comparatively recently brought into use. The reason of that seemed to be because the framing as it used to be devised, consisting of cast-iron columns without much lateral stay in the form of horizontal girders or diagonal tie rods, had comparatively little lateral strength, and that therefore to add more pressure to them than the mere push outwards would hardly be advisable; whereas of course in the modern system the horizontal girders and stiff diagonal bracing and so on were brought into play and the pressure on one column was distributed gradually to the others, and finally to the ground where it was resolved into the tensional pull upon the holding-down bolts. Mr. Pease stated that the maximum wind pressure over half the total sectional area acted upon by the wind was 40 lb. There seemed to be a great difference of opinion on that subject. Messrs. Newbigging and Trautwine both agreed with

Mr. Pease, but Mr. Cripps only took 32 lb. as likely to come upon the holder. Taking 50 lb. as the maximum wind pressure they were likely to get, meant only about one-third of the diagonal sectional area. Mr. Adams referring to the amount of wind, took 0·7854 of the sectional area; Hutton took 0·67; Molesworth 0·75; Rankin 0·75 of the diametral section as the equivalent plane surface equal to the cylindrical area exposed to the wind. The author had added 90 tons. He said, "The lowest portion of the light sheeting of the second lift, consisting of $\frac{3}{16}$-inch sheets, may be considered to be the first point at which buckling or crumpling would make its appearance. This, however, cannot take place until the vertical tension of 90 tons and the latent strength of the sides of 80 tons have been overcome, together equal to 170 tons." Surely that latent strength was the strength which would resist compressional strain and only came into play when the tensile strains were being considered.

With regard to the use of channel iron stiffeners, they were necessary for another purpose besides stiffening the side of each lift. When placed on either side they prevented the bulging of the sheeting which would otherwise run against the curb of the next outer lift, and he had even known gasholders which had very strong channel iron stiffeners to bulge out so much that they had rubbed against the rivets and the half-round iron which was placed on the grip of the next lift. There was also a point with regard to the arrangement of the ropes in Mr. Pease's invention. In that case the ropes were placed vertically, but it seemed to him (the speaker) that the strain was not in a vertical direction. If the ropes were placed at an angle as large as could be allowed according to the space which was available round the edge of the tank, the pull would be more in the direction of the strain. If the holder started to tilt the axis would be practically in the centre of the holder and at the level of the water, and therefore the pull was really at a tangent from a line drawn from the centre of the holder to the upper curb where the rope first went over. On that account a rope so placed was not in its strongest position. It could be arranged as he had stated. Some years back he briefly discussed this question with the author, but it was not then convenient to him to point out exactly the method by which he could arrange the ropes. It seemed to him that it would be an advantage to obtain as much strength as possible from the wire ropes which were used.

With regard to the framing of a gasholder as now made of steel and wrought iron, it seemed that the best thing was to make a frame which would contain as few compressional members as possible. He had recently been studying the question, and he had arranged a framing in which the only compressional members would lie in the standards themselves. There would be no horizontal girders which would be sometimes in compression and sometimes in tension. In Messrs. Cutler's diagonal system of framing for instance, the framing was sometimes in tension and sometimes in compression, according to the direction of the wind, the change of strain causing a loosening of the joints. In the framing he had devised the only compressional members would be in the standards and those only for a very short distance.

Mr. R. J. G. Read said many years ago when he was connected with the Gas Light and Coke Company at Beckton the standards were constructed of cast iron. They were formed of segments bolted together with horizontal joints and were made exceedingly heavy. It appeared to him that they were very much too strong for the work which they were required to do. He had watched with interest the transitions which had taken place since in the shape of the standards. He had recently seen a modern gasholder being erected at Kensal Green alongside the old ones, with standards of latticework about 160 feet high, and they were so stable that he was informed one of them stood upright by itself through a windy night. The framing of the gasholder which was erected by the South Metropolitan works was carried to a very fine limit of lightness. Sir Benjamin Baker was consulted on the subject of its stability by Mr. Livesey, and he went into the question of the strains on the holder and framing, and his report was a very instructive one. His general conclusion was that although the framing was so light, a hurricane of sufficient force to blow down Charing Cross Station would only strain it to about 5 tons per square inch. He (the speaker) thought that the power of the gasholders, made without outside stanchions, to stand by themselves, was due to their breadth compared to their height, and to the power of the column of gas inside to make them rigid. He considered it would be a disadvantage to do away with the stiffeners in the sides of the holder sheeting, because unless there was some stiffening to resist the compression, the sides would go in something like the side of the silk model exhibited, and if the action was continually repeated the sheets would suffer very severely from the alternate strains. It was a very bad plan to subject a bar to alternate compression and tension if they could avoid it.

Another thing which struck him was that the immense power to resist distortion which those holders showed was in a great measure due to the immense surface of plate which offered resistance to tension; he wished to know what pressure per square inch the author had reckoned that the stiffeners could withstand. Although four or five tons per square inch might be reckoned on, still when a gale of wind came on the holder the bars must be strained beyond their elastic limit before the holder could be distorted, or begin to show signs of buckling. Therefore there would be an immense amount of strength in reserve due to the factor of safety. No doubt cast-iron columns would be far better able to withstand the corrosive action of the gases than wrought iron; but on the other hand he had found that the great outcry against wrought iron on account of its rusting and the painting which it required, was in a great measure due to the very inferior paint which was often applied to it. Good oxide paint ought to contain upwards of 70 per cent. of pure ferric oxide in the paste state; but he had examined a sample of paint which was being used at a gas-works to paint a holder with, and found that it contained only about 15 per cent. The rest of the paint consisted of impurities and adulterations. Very great attention should be paid to the paint which was used for painting any new structure of iron. The paint ought to be tested thoroughly, and taken not on repute, but on analysis.

Mr. W. H. Y. Webber said that gasholder construction was a growth, sizes being increased from time to time as necessary, and gas engineers had not had time to pay attention to the economics of construction, and no one thought it worth while to investigate the subject until Mr. George Livesey took it in hand. Cast-iron columns made heavier and heavier were not necessarily stronger, and he had heard Mr. Corbet Woodall say that he had seen a cast-iron column drop in halves as it was being lifted. He thought that fact demolished what had been said by one or two speakers as to the superior strength of cast iron as compared with wrought. It might seem curious that no one before Mr. Livesey had asked himself what was the office of the framing of a gasholder, and how much of that office did the framing fulfil. Mr. Livesey by that method of inquiry had arrived at the daring results with which engineers were familiar. He looked upon what had been done hitherto as only a beginning.

Mr. Gandon had told the meeting that he had been almost persuaded to be a wire-ropist, but he preferred somebody else to try first. Probably everybody who was responsible for large works felt very much like that. No amount of saving of cost would compensate for incurring the slightest risk in the stability of a gasholder. On the other hand, it was not justifiable to assume that because framing was heavy and costly it was therefore strong. The 712 tons of support which Mr. Pease had mentioned was not necessarily an atom stronger than that which weighed only 128 tons; and no multiple-lift gasholder could ever be regarded as a thing which did not require looking after. The doing away with the vertical framing was a step in advance, for the framing was a trouble, and it was a question whether it was not better to have no framing than one which was more of a pretence than a reality. He regarded Mr. Pease as one of the most philosophically minded experimenters on the subject. He had gone into the matter with a clear idea of trying to find out what the ropes did; and yet that was a point which was not to be found in the paper. He would ask Mr. Pease whether he had ever put a dynamometer spring on any of the ropes in order to find out exactly what the ropes did. He was not sure that a gasholder really put more strain upon its framing in a gale of wind than in a calm. Of course a loosely framed gasholder did. When he first made acquaintance with gasholders they were purposely made loose, so that there should be no difficulty in going up and coming down, and a loosely framed holder would "wobble" about in a most alarming manner, and put a tremendous amount of strain upon its supporters. But, as an old foreman of a gasholder builder's once said to him, "Get the bottom holders right and the top ones will take care of themselves." As long as a gasholder was held fairly tightly both at the top and at the bottom by rollers, by ropes, or by anything else, the influence of a gale of wind was really nil. The weight of the structure itself was quite sufficient to neutralise the wind.

Mr. Gandon and Mr. O'Connor both assumed that there must be extra weight in the plates when the gasholder was made, so that it did not lean up against outside vertical guides; but he did not think that that at all followed. The gasholder sheets must be made stout enough to stand the necessary scraping and knocking about which they got in the ordinary way, but there was no need to reckon anything else. If a gasholder was strong enough to withstand ordinary wear and tear, it would be strong enough with any sort of framing which they liked to put round it. It was not correct to say that tangential rollers had only come into use after columns were supplanted by standards with diagonal framing. They were a French invention, and they were put up with the old-fashioned style of columns. The object of using them was to distribute the weight upon two points instead of confining it to one. An example of them was given in King's 'Treatise on Gas Manufacture,' in the case of a gasholder designed by MM. Monnier and Thibaudet for the Marseilles Gas Company.

Some wise engineer, speaking of the ordinary assumption of the "factor of safety," had called it the "factor of ignorance." He (Mr. Webber) thought that that remark applied particularly to the whole subject of the strength which ought to be put into the various means by which gasholders were maintained. Engineers were now working in the dark and erecting these structures tentatively; and it was only from careful experiment that they would know what the framing really did, and to what extent it might be cheapened. The cost of an ordinary fixed outside framing after the old style might be materially reduced by the selection of ordinary commercial patterns, and the proportioning of the framing to the work which it had to do. The expense was a question of design, as well as of weight of material.

Mr. J. L. CHAPMAN said he was very much with Mr. Webber in regard to the present subject. The question was between gasholders with columns and gasholders without columns. He thought that the experiments which had been made up to the present time showed that the expense of an uncolumned gasholder was almost as great as that of a columned one. There was no doubt that the strength of gasholders' columns exceeded what was necessary, but, as had been remarked, engineers did not like to make alterations unless they were certain as to stability. It was not perfectly clear that the wire ropes would be sufficient to guide the gasholders, as had been ably stated by Mr. Pease. One came to the consideration of such a subject prejudiced by his own past experience, and it was difficult to plunge into a new theory all at once. Probably gasholders would look much prettier without columns.

Mr. PERCY GRIFFITH said, the author, in referring to existing types of gasholder framing, had dealt somewhat cursorily with them. He had condemned very generally, owing to excess of weight, and consequently (he took for granted) the excess of cost, the old-fashioned standard guide framing. Mr. Pease had given three instances, comparing variations in weight of columns and girders, which, to say the least, were very remarkable. He should like to know something more about them because there might be some explanation which did not appear on the surface for much of the difference between them. Having briefly referred to the development of gasholder framing, the speaker said it appeared to him that, in the book referred to by Mr. Gandon, Mr. Cripps had swept away a good deal of the misconception which existed as to strains on gasholders; and if the conclusions to which he came could be taken as anything like correct, a new condition of affairs was apparent. The strain on the holder was found to be best resisted not by a single cantilever, which had its whole strength relying upon its own individual base, but by the construction of a cylinder round the holder forming a complete framing in itself, and having strains in it which were very different indeed from those of the cantilever. It was in following out this theory that he (Mr. Griffith) designed a holder which was constructed, he thought, as cheaply as it was possible for a holder to be. Calculating on the basis of Mr. Cripps's formulæ and from his reasoning, the standards, instead of being cantilevers, became simple compression members; the diagonal tie-rods taking the tensional strain. There was no tilting force exerted upon the standards; therefore the standards did not need to be wide. Their strength was simply in concentrated cross section, and not distributed in the form which the cantilever latticed standards took. The difficulty of painting and getting at the latticed standards was overcome by these means, because, in the case referred to, the standards were nothing more than rolled iron joists of a standard section, and could be bought at from 5*l.* to 6*l.* per ton. The tie-rods also were nothing more than round rods, and were joined to the flanges of the rolled iron joists. The construction was so simple in the form and design and jointing, and there were also so many advantages with regard to the maintenance, painting and so on, resulting from the simplicity of the structure, that he thought this type of holder would present very serious rivalry to holders without guide framing.

The only objection which arose in his mind to going into anything so entirely new as Mr. Pease's system was the absence of exact knowledge on two or three points. The calculations which had been given with regard to the strength appeared to be somewhat elementary in character; and it struck him that the paper might have been more useful if it had contained a little more detailed calculation, which they could have studied at leisure. They had 40 lb. per square foot given as the wind strain. His own experience was that the wind pressure must be taken as a good deal more than that—even as much as 56 lb. Supposing, however, they took as correct the calculation given, it proved that the holder was strong enough in itself to resist contortion; and that left only the tendency to tilt. Now the strains on a holder became very complex indeed as soon as it got the slightest degree out of the horizontal; and the strains on the fixed internal members of the holder, on the curb and so on, became suddenly very great—a slight amount out of the horizontal would produce that effect—and he should have liked to have had a little more calculation in respect to that point. He also asked the longest time that a holder of any reasonable size had been erected, and whether any test had been made with one fully inflated during the recent gales.

Regarding the use of wire ropes, there were some rather sharp bends on gasholders; and he would like to know whether any perceptible wear upon the ropes had been found, and whether any weak points had been discovered where they worked over the pulleys. Also whether a holder had been tested to the point of collapsing, so as to illustrate where the collapsing actually occurred, and to test the actual strain upon the ropes. Those were investigations which he thought any engineer designing such a holder would want to know something more about. What happened, too, when the holder blew? or did the ropes prevent it doing that? because if they did it would be a great objection, as it would throw considerable back-pressure on the retorts, or the exhauster, or some other part of the plant.

In one part of his paper, Mr. Pease gave as the resistance to buckling the sum of the tension resistance and compression added together. If the plates were only in tension, it was useless to consider their strength in compression; and if the side of the holder came into compression, why consider its strength in tension? They could not add the strength and resistance of compression to the strength and resistance in tension, because they were two very different things, and could not act at the same time.

Mr. C. J. **Brown** said that, with regard to the wear on the wire ropes, he might be able to give the meeting a little piece of experience which had been given him by the manager of a large gasworks and consulting engineer to a number of collieries in South Wales. Having examined into the question, he said to him (the speaker), "Well, I have examined wire ropes working under all conceivable circumstances. I have a wire rope working now over a pulley making 500 revolutions a minute, and I think that a bed-ridden man's shoes will wear out as fast as these will."

The President said he had had the pleasure of seeing the South Metropolitan gasholder to which reference had been made. It had an enormous amount of bracing upon it, and he had been told that Sir Benjamin Baker had been called in, and at his suggestion an extra amount of bracing had been added to it. Such a recommendation, coming from such a man, seemed to show that, in his opinion, outside bracing was not altogether to be depended upon. If the author could state the reason why that recommendation was made, the knowledge would be valuable to the Society. It had been suggested by one or two speakers that if the columns were dispensed with the sides must be increased in thickness. Mr. Webber was of opinion that that was not so. He would ask the author to answer that point definitely. With regard to Mr. Griffith's remark as to the pressure of the wind, he (the President) must say that he thought that 40 lb. over a large area like that of a gasholder was very high indeed, though the local pressure over a few feet might even go up as high as 56 lb.

Mr. Pease, in reply, prefaced his remarks by admitting that his paper was only intended to be suggestive, and not highly technical, as he could not pose as an engineer. The bracing of the last gasholder but one of the South Metropolitan Company was increased during the period of construction. Why it was increased he did not know. There was now a double set of bracing in each bay; but as that holder relied almost entirely on its bracing, and very little on the stiffness of its standards, it was probably desired to have a large margin of safety in the bracing. With regard to the thickness of the side sheeting, he really could not see that there was any necessity to make the sides any stronger than they were now. He quite agreed that there were many uses for channel iron vertica stays, and that they had better not be dispensed with. Many holders were built so close between the cup of one lift and the sides of the other—within two or three inches in some cases—that the very slightest amount of irregular construction of the side sheets would bring the rivets on the side sheeting agains the cup of the next lift. That, however, was more the fault o the design than of the construction. As to the pressure of the wind, he mentioned 40 lb. as a figure easy to work with, and i was on the safe side. In gasholder construction they did no sail very near the line, so that taking 2 lb. more or less wa not an important matter. He did not know that there had been any reliable information secured by anybody as to the pressure of the wind over such an extensive surface as that o a gasholder.

Mr. Gandon made some remarks as to the figures given relating to the three gasholders alluded to in the early part of the paper. The first two were really reliable comparisons, as in both cases the columns were cast iron and the girders wrought iron, and they showed a sufficiently large increase to make the point. The third holder was one that was exported to Australia, and no doubt the weight was cut down on account of freight. With regard to the buckling of the sides of the silk model to which reference had been made, it was an illustration largely of the use of channel iron verticals. The silk model had no vertical stiffeners, there was nothing but silk, and therefore it could not carry its own weight. In proportion the model was much weaker than a gasholder with vertical stays; but if it was strutted up with verticals there would probably be no buckling, even with the weight which had been put upon it —6 lb. Mr. Webber had made some remarks as to the possibility of instituting some experiments as to the pressure a gasholder would withstand. As to the making of experiments, none had been made with a gasholder of any size—certainly not with an iron one, that he was aware of; but some time ago he (Mr. Pease) had carried out some experiments with a 5-foot holder, constructed of brown paper, in order to see the weight it would stand simply inflated, and to get an idea as to how it would collapse under very great pressure. It stood a large amount of pressure—he forgot how many 100 lb.—but there was hardly an appreciable bend in it, though there were lines of distinct corrugations.

Mr. Webber observed that his point was not the strength of the side sheeting, but the actual stability of the vessel.

Mr. Pease said that that was another point.

Mr. Webber said that he had for years held the opinion that if the vessel once began to get out of the perpendicular, no strength that they could put on the side framing, by ropes or anything else, would hold it up.

Mr. Pease said he did not see it in that light, but still it might be so. It was pretty plain that the wind pressure had to be resisted; but if the ropes were off or attached to different points, it would be seen that the very slightest load on the side of the roller would tilt it over; and if it would do it with a vertical pressure, why should it not do it with a horizontal pressure like the wind? Besides the wind, there was the weight of the snow which had to be arranged for. He was perfectly aware of the elementary nature of his calculations. He had not presumed to bring before the meeting a mass of calculations. As he had said, the paper was suggestive of one or two points that had not been alluded to before. He might specially mention the fact of the strength the holder exhibited even when it was uninflated and standing on the rest-stones. The strength, as he had tried to emphasise, was still in existence during inflation, and no buckling could take place till that initial strength had been overcome. That was why he had —perhaps rather irregularly—added together the two figures making the 170 tons. As to the length of time these holders had been in use, the first one was put up in 1889, and had been working regularly ever since; others had been subsequently erected. There were now a very considerable number in existence. The ropes of the first holder erected at Manchester did not show the slightest sign of wear, though they had been working ever since 1890. The pulleys used were about 12 inches diameter. Then, with regard to the question as to whether a holder of that kind had withstood any great strain, he had been informed by letter from America that a two-lift holder constructed on that system was fully inflated whilst a cyclone passed across the town, and it stood unharmed.

Fig. 1.

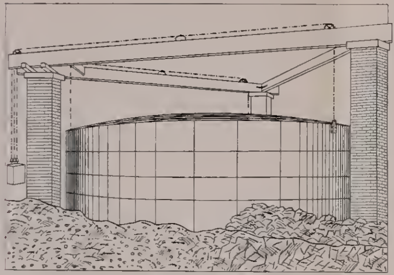


Fig. 2.

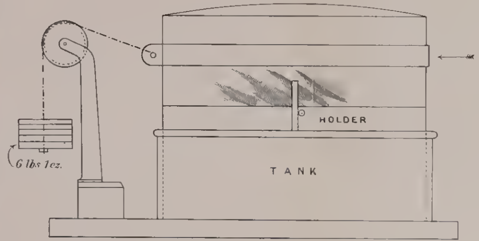


Fig. 3.

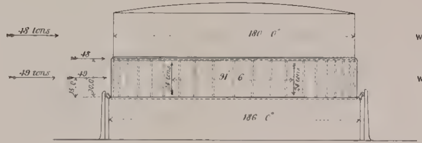
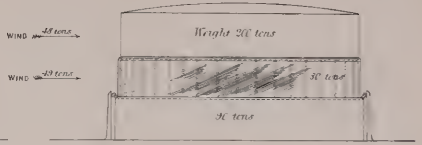


Fig. 4



Pressure all bits inflated 5 9/10

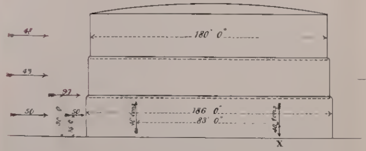


Fig. 5

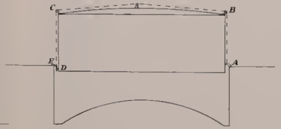


Fig. 6.

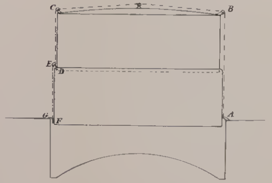


Fig. 7

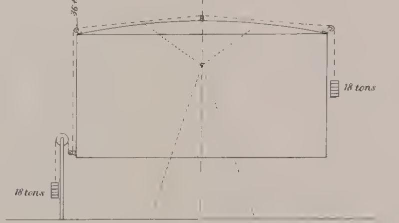


Fig. 8

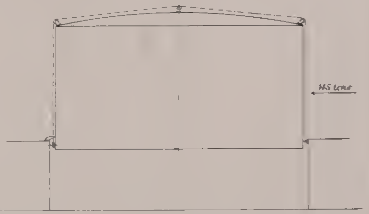


Fig. 9

E & F N Spon London & New York

May 7th, 1894.

GEORGE A. GOODWIN, President, in the Chair.

A DEEP BORING NEAR FREISTADT, AUSTRIA.

By Robert Nelson Boyd.

In the present paper the author describes a deep boring carried out near Freistadt, Austria, on the Canadian system. By way of introduction to the main subject he will give a few particulars respecting deep borings in general.

The art of boring for minerals has been practised by miners for centuries, but in past times the depths required and attained were shallow as compared with the present. The first bore-holes were put down by hand labour, that is, by drawing up the rods and cutting tool, either directly with the aid of a rope passing over a pulley, or indirectly by winding the rope round a winch. Subsequently steam-power was applied to the winch, but the rope was still held by hand, and the action of the cutting tool in the bore-hole was effected by raising it up a few feet and allowing the rods and the tools to drop with the force of their entire weight. The rods consisted of 1 inch or 1¼ inch square iron, and great difficulties were found in boring deep holes; first, by reason of the weight of the rods, and secondly, on account of the jar or vibration they sustained at each blow of the chisel. The limit of depth to which borings on this system could be carried was usually taken at 1000 feet. It is true that the Chinese have sunk bore-holes to a depth of several thousand feet, by means of a cutting tool resembling the modern chisel, weighing with sliding piece from 200 to 300 lb., and attached to a rope passing over a pulley, which is pulled up by hand several feet, and then allowed to drop. The time, however, required to sink these deep holes was reckoned not by years but by generations. In course of time, as it became necessary to sink to greater depths, improvements had to be introduced in the construction of the tools, and the arrangements of the mechanical gear used to supply the motion to the cutting tool in the well or bore-hole. Thus, the walking beam was applied, set in motion by a steam engine, and the "jars" and "free-fall" tools were introduced to relieve the rods from the vibration consequent on the blows of the chisel on the bottom of the bore-hole. Some such apparatus was necessary in order to prevent many accidents, which otherwise would occur in deep holes, through the breaking or bending of the rods or the falling in of the unprotected sides of the bore-hole caused by the vibration of great lengths of iron rods. The introduction of these latter tools has been followed by a complete revolution in the art of boring, and has enabled depths of several thousand feet to be reached with a rapidity and economy not formerly possible. The deepest boring up to the present time, so far as the author is aware, is that of Schladebach in Prussia, which is 5736 feet deep.

The so-called "jars" (Fig. 1) consist of two flat links of steel attached directly under the rods or rope, so that when the chisel strikes the bottom of the bore-hole the upper link follows down until the stroke of the engine is completed, leaving the lower link and the tools alone to sustain the shock of the blow of the chisel. The links must be longer than the stroke of the engine beam, and in the Canadian rig they are generally 2 feet 6 inches in length. The "jars" were first applied to boring, in 1834, at a bore-hole at Neusalz, in Germany, by the Government engineer, Oeynhausen. This bore-hole was sunk to a depth of 282 metres 51 c. (equal to 927 feet) with the usual tools, but by the application of the "jars" was subsequently carried down to a depth of 2252 feet. The "jars" were soon replaced, on the Continent of Europe, by the Fabian free-fall tool (Fig. 2), where it was first applied by M. Kind in 1844. The principle of this instrument consists of an arrangement by which the cutting tool is lifted with the upstroke of the walking beam and then released by means of suitable mechanism, allowed to drop, and give a blow in proportion to the weight of the tools and the length of the drop. In the Fabian and similar free-fall instruments, a rod to which the cutting tool is attached works in a tube or box. At the top of this rod is a pin, which by turning the rods slightly from the surface engages in a slot, and is thus raised by the upstroke of the beam. Then, generally by bringing the free end of the beam down on a block of wood, sufficient vibration is caused to disengage the rod in the box from the slot, and in combination with a turn of the rods by the driller, the chisel falls freely to the bottom of the bore-hole. This is the most simple contrivance, but sometimes the vibration is produced by bringing the end of the beam to which the tools are attached in contact with a properly fixed block of wood on the upstroke. The concussion, however, produced is considered by the advocates of this system of boring to be of great importance, as it limits the stroke, facilitates the turning of the beam, and liberates the free-fall tool. It must here be mentioned that a number of free-fall instruments have been invented to enable the cutting tools to be released without the aid of any concussion.

It would hardly be within the scope of this paper to enumerate them in detail, suffice it to refer to one or two of them. Thus Kind has a disc of sheet iron fixed on the top of the free-fall instrument, which is acted on by the column of water in the bore-hole, and thus sets a click in motion which liberates the cutting tools. This arrangement implies the presence of a column of water in the bore-hole. Again, Leon Dru depends, in one of his inventions, on the slight momentum acquired by the tools, below his apparatus, on the upstroke to loosen a catch moving on a joint, which holds the tools, and on the downstroke the rods act on this catch so as to free the tools which then fall to the bottom of the well. The box containing the catch follows down, and the tools are again caught up and raised.

In the Continental boring apparatus the power is generally obtained by means of a single acting steam cylinder applied directly at or near one end of the working beam, the rods and tools being attached to the other end. The steam power is applied to raise the rods up, and the downstroke is effected by gravity. In this system of boring, iron rods are always used, and they are partly counterbalanced by weights attached to the end of the beam in order to reduce the work of the steam cylinder, and a second small engine is required for lowering and raising the rods, tools and sand pump in and out of the bore-hole. A general outline of the rig is shown in Fig. 3.

The object of this paper is not to describe the various systems of boring in detail, but it has been considered advisable to allude to the free-fall instrument as distinguished from the jars, one or the other being applied in nearly all the methods made use of in deep borings. There are several systems in which these tools are not required, as for example, the diamond drill, the water pressure system, applicable to soft measures only, and Messrs. Mather and Platt's invention, by which the chisel is attached to a flat rope and falls with its full weight on the bottom of the bore-hole, a fall which varies, according to the size of the machine and the nature of the ground to be bored through, from 2 feet to 16 feet.

The experience of the author in boring deep wells for petroleum showed that the Canadian rig and tools, in which the jars are adopted, was preferable to any of the systems involving the uses of the free-fall instrument, on account of the greater rapidity of boring attained by this system. The Canadian method originated in the early development of the petroleum fields of Petrolia, Ontario, which followed shortly after the first oil well was put down near Titusville, Pennsylvania, in 1859. At that time the so-called wells or bore-holes were sunk by hand, and in this operation iron rods have always been and are to this day generally used. It is probable that the early Canadian drillers adopted ash poles (Fig. 4) in lieu of iron, in order to reduce the weight, and subsequently, when steam engines were introduced as motive power, they selected the American drilling tools (Fig. 5), and in so far the Canadian method of drilling may be described as a modification of the American, the only difference being that in the former, ash poles are used, and in the latter, a rope to convey the necessary motion to the cutting tool or chisel at the bottom of the bore-hole or well. In the American method the so-called "jars" or "slips," consisting of two flat links of steel, in place of the box and catch used in the free-fall system, have always been used.

One advantage of the jars among others, lies in the continuous and rapid working of the apparatus. In good drilling ground it is not exceptional to run at the rate of 60 and even 70 strokes a minute, either with wooden rods or ropes. The jars were adopted in America on the application of steam power in conjunction with the heavy tools necessary for drilling with a rope. In the United States the rope is generally made of hemp 1¼ inch diameter, and is kept taut by means of heavy weights termed sinker bars, and these, together with the string of tools, make up a total weight of about one ton. This arrangement has been most successful in sinking deep wells in the oil regions of the United States. It is especially adapted to the stratification of the ground in Pennsylvania, where the beds lie at a gentle inclination and consist mostly of sandstone and slaty shales, which are easily bored through, and yet are sufficiently firm to stand without the necessity of casing or lining. The oil and gas wells of the United States attain a depth of over 3000 feet, and are economically sunk by means of the rope system. In boring to a great depth in Pennsylvania it has been found advisable to use a flat hemp rope instead of a round one. Steel ropes have been recently introduced, but have not been as yet adopted generally.

In Canada, where the wooden poles are customary, the depth of the wells does not exceed about 500 feet, and as the ground is exceptionally easy for drilling, as much as 100 feet can be sunk in a day. In the Petrolia oil field a good set of drillers reckon to finish a well, that is to a depth of 500 feet, within a week. Similar results have been realised in Galicia, and in good drilling ground, over 100 feet a day have occasionally been sunk. But rapidity of drilling by this method can only be realised in wells of moderate depth, because the time occupied in screwing and unscrewing the rods is considerable, and in deeper wells the advantage as to speed belongs to the rope system. In order to exemplify this, the author is able to give the following record of the time occupied in drawing and letting down the rods at a deep well in Galicia, Austria, as noted by himself. The well at the time was 470 m. deep, i. e. 1542 feet, and was sunk by competent drillers.

	Minutes.
Drawing up the rods	25
Letting down the sand pump by means of rods	14
Drawing it up	24
Changing the chisel	3
Letting down the chisel	14
Connecting the beam	5
Total	85

The author observed the same operation performed, with the rope, for a depth of 1600 feet, in the Bradford oil district in Pennsylvania, when the time occupied was found to be about 20 minutes.

A small wire rope worked by separate gear is sometimes used for lowering, working and raising the sand pumps, in which case the 85 minutes mentioned above would be reduced to 55 minutes. But this arrangement cannot always be applied. For instance, in Galicia, Austria, where the Canadian system of drilling has been successfully introduced, it is the custom to line the bore-holes with riveted sheet-iron casing, instead of lap-welded tubes, for reasons of economy, and these are put in telescope fashion, leaving the inner length of casing slightly projecting. It is evident that it would be absolutely impossible to keep the sand pump perfectly steady in its rapid descent, and consequently the danger would arise of striking the projecting rims of the casing and thus damaging, and perhaps destroying, the well. The experience of the author justifies him in condemning this mode of lining oil wells. The first cost is certainly much less, but the economy is more apparent than real. In bad ground the sheet-iron riveted pipes are apt to bulge in, and owing to the loose riveting and the open space at the junction of each string of casing the lining of the bore-hole cannot be perfect. Moreover, if the well yields oil for several years the thin wrought iron is certain to corrode, and fresh casing will have to be put in. Lastly, the sheet-iron casing would not bear moving and cannot be drawn out of the well when it comes to be abandoned. In a trial boring intended only to explore the strata, the short life of the casing is not an important factor, and in this respect sheet iron may be used.

The so-called Canadian drilling rig as used in Austria, and in the boring to be described (Fig. 6), consists of a derrick or staging, 56 feet high, 16½ feet square at the base and 3¼ feet square at the top. This is usually constructed of timber; but of late years derricks of wrought iron have been introduced, which have the advantage of being easily taken to pieces, removed and put up again. In the front of the derrick is a narrow door, about 15 feet high, to enable the tools and casing to be taken into the structure. The engine is fixed in a shed adjoining the derrick. The boiler is placed in another shed at some distance, when the boring is for oil or in strata likely to emit explosive gases. The derrick is close boarded. It is supported on "runners" or sleepers which are fixed on baulks of timber termed "mudsills." The engine is of a simple horizontal construction, having one cylinder 10½ inches diameter and a flywheel. On the flywheel shaft there is a pulley which drives by means of a strap the band wheel which is about 5 times the diameter of the pulley. This band wheel works one end of a walking beam up and down by means of a connecting rod attached to it by a pin, revolving in a circle about one and a half time the diameter of the pulley. On the other end of the walking beam is fixed a spring pole sustaining the drilling tools, by means of a short piece of chain, gripped in spiral cast-iron grooves firmly fixed on the end of the spring pole; this chain is wound round a reel fixed on the walking beam about the position of its fulcrum. On the lower end of this there is an attachment screw fixed on a swivel, which fits others on the rods and tools. The swivel enables the driller to turn the tools round, an operation which is necessary in all kinds of drilling where a simple bit or chisel is used, in order to keep the hole round and the bottom level. The apparatus is designed by the oscillations of the walking beam to give an up-and-down movement to the rods and string of tools in the bore-hole. In the rig used, the fall allowed was 18¾ inches. The reel above named enables the chain to be payed out as the boring descends, by means of a "slipper out," which is a combination of pawl and ratchet acted on by a string at the command of the driller.

Besides the drilling apparatus proper there is another appliance attached to the engine for removing or replacing the various tools in the boring. When it is to be worked, the walking beam connecting rod must be disconnected, then the driller, by the aid of a brake, can control the appliance, which consists of a winch capable of winding up on its barrel a length of rope equal to the length of one of the rods. This rope is carried over a pulley at the top of the derrick and terminates with a heavy cast-iron weight called a "cow-sucker" to bring the rope down to the level of the bore-hole. It is not necessary here to catalogue all the tools used in the Canadian system of drilling, as most of them are common to all methods of boring; suffice it to state that a string of tools (Fig. 5) consists of the jars, sinker bar, guide and chisel. It is frequently necessary to undercut in the process of boring, for which purpose an instrument called a "rimer" is resorted to. The rimer used in the boring at Freistadt was fixed about 2 feet above a chisel of smaller diameter, and consisted of two projections or wings of steel slung on pivots, which were pressed outward by means of a spiral spring, so that while being lowered down in the casing the wings rubbed against the sides, but immediately they reached the bottom of the casing they sprang out and cut away the ledge left by the chisel. All the tools are fitted with conical screw joints, and it is important that these joints should have exactly the same thread, so as to be interchangeable. As the poles are drawn up they are received and detached by a workman at the top platform of the derrick, while the driller at the ground level rests them on the wrench block, a piece of timber covered by sheet iron, and having a rail at one end to prevent the poles from sliding off.

The combination of parts in the Canadian apparatus is designed to give the driller complete control, within limits, over the velocity with which the chisel strikes the bottom; the highest velocity of the chisel being that of the end of the walking beam when its movement brings it to a horizontal position. The driller regulates the velocity of the tools in accordance with the nature of the ground to be bored through. It is needless to state that he has the engine under his control by means of a cord communicating with the throttle valve. The velocity of the chisel in the free-fall system is that due to the height from which it is allowed to fall, which does not exceed about 4 feet.

The rig thus succinctly described was the one used in the boring undertaken for the purpose of an exploration for coal in Austria, the details of which form the subject of this paper. However, before deciding on the adoption of the Canadian method for this purpose, the advisability of using the diamond drill was considered, and a shaft was sunk to a depth of 30 feet, to ascertain the exact nature of the strata near the surface. The only advantage of using the diamond drill would have been to secure a core of the carboniferous rocks, and identify them with the known beds found in the pits of neighbouring collieries. Otherwise the diamond drill is not reliable for proving coal properties. A core can only be secured in passing through hard ground, and in the carboniferous measures, the clays, soft shales and coal seams, unless of a very hard nature, may be passed through without obtaining a core or record. In this case, however, the overlying Tertiary beds were of such a nature and thickness that the diamond drill would have been quite inapplicable.

The bore-hole was put down in an unexplored part of the Austrian Silesian coal-field, known as the Ostrau Karwin Coal basin, which is situated close to the north-west frontier and forms an extension of the Prussian Silesian coal-field. It is the only important deposit of Palæozoic coal in the Austrian dominions; lignite and other coals exist in great quantities in Bohemia, Carinthia, Hungary and other provinces, but Palæozoic coal only in the Ostrau Karwin coal-field and over a very small area in Bohemia. The importance of this coal-field to Austria can scarcely be overrated, as it is the only source of supply of coke and iron furnace coal in the country. The basin, so far as known at present, extends from Schönbrunn in the west, to Karwin in the east, a distance of about 24 kilometres (15 miles) and the average width is about 1 mile, so that the basin as known covers an area of 15 square miles. The seams proved up to the present time number 26 with an aggregate thickness of 43 m., more or less. These seams are not all workable, but 13 are over one metre thick, and one of the lower beds attains a thickness of 8 m. 16 c., with a small clay parting of 46 c.

The end of the coal formation to the north and west is well defined by an outcrop of culm beds. Towards the south the boundary is also defined by limestone of the secondary period. But in the easterly direction at Karwin, where the seams are being worked without any signs or indications of a break beyond ordinary faults, the end of the coal basin is not defined. The greatest part of the basin is covered by beds of clay belonging to the Tertiary formation, varying in thickness from a few yards to 250 yards. This deposit of Tertiary clay is considered by Austrian geologists to be similar to the beds of the Vienna basin, and is locally known by the name of "Tegel." It is divided into two beds, of which the lower one is so tough that it has to be blown down with gunpowder in sinking shafts, but in the presence of water and air it soon disintegrates and swells, so much so, that sinking through it is a difficult and expensive operation. It contains small quantities of chloride and iodide of sodium. The two beds of this tertiary deposit are considered by Herr Stur to be identical with strata on the shores of the Mediterranean, and he classifies them as Neogene, a name given by some Continental geologists to the groups of Pliocene and Miocene strata.

To the eastward of the existing pits, this clay deposit continues, and until lately there was no positive evidence as to its thickness in this direction. However, some years ago a bore-hole was sunk about a mile east of the extreme easterly coal workings to a depth of 269 yards into the clay without passing through it. This bore-hole gave out a great quantity of coal gas, so much so, that an explosion occurred in the drilling shed, which destroyed the machinery and stopped the bore-hole; and it was assumed from that circumstance that the coal seams were not very distant. The great probability of the coal seams extending towards the east of the basin was also supported by the fact that the Prussian Silesian coal-field lies in that direction, and the Ostrau Karwin basin has always been accepted as forming part of this extensive field.

These and other facts drew attention to the advisability of putting down a bore-hole to test the extension of the coal. A concession of some 2000 acres was secured by lease, and this boring was undertaken for the purpose. In the western part of the basin the Tertiary deposit has an average thickness of from 50 to 100 yards. In some points the coal measures crop out to daylight, and at others they are covered by the Tertiary deposit to a thickness of 250 yards. At Karwin, the extreme eastern point of the basin under exploitation, the thickness of Tertiary clay is 90 metres. Beyond this point towards the east nothing was done to discover the continuation of the coal measures except the bore-hole already referred to, until it was decided to put down, under the direction of the author, the bore-hole now to be described.

About 2 miles to the north of the workings of the Karwin coal pits the river Olsa flows from east to west, and it was supposed possible, that through erosion, a considerable part of the upper coal measures would be washed away in the valley of the river and replaced by Tertiary deposits. The bore-hole already alluded to was the only exploring work carried out, and this proved 246 metres of clay and the presence of inflammable gas. The bore-hole under consideration was placed on rising ground about 2½ miles from the extreme easterly workings of the Karwin collieries and 1¼ mile from the old bore-hole, and was assumed to be favourably placed at the edge of the valley of erosion and in the direction of the general strike of the coal seams. In view of the nature of the ground at Freistadt it was considered advisable to commence the boring with a diameter of 18½ inches, which was carried down to a depth of 26 m. 60 c., when the caving necessitated lining the bore-hole, which was done with sheet iron casing made of plates 3 mm. to 4 mm. thickness (about ⅛ inch). (See section, Fig. 7.) The boring was then continued within this lining with a chisel 17½ broad, down to 96 m. 47 c. and again lined with sheet-iron casing. This string of casing was armed with a steel shoe and driven down from the surface by the walking beam. Within this the next length was put down with a 16-inch chisel a depth of 141 m. and lined with casing 14 inches in the clear. This was also driven from the top so that the upper three strings of casing were put down from the surface.

The next length was bored with a chisel 13⅓ inches down to 40 m. 95 c. and lined with a 12-inch casing. This casing was not put down from the surface but telescoped in the outer casing. It was also armed with a steel shoe and it was attempted to force it down, as the upper casing had been forced, from the surface, but this was not very successful and the attempt to force the casing below this was abandoned. The boring was continued with a chisel 11¾ inches down to 32 m. 80 c. and lined with 11-inch casing which telescoped with the upper casing for about one metre. The next chisel was 10½ inches and the casing 9 inches, length 23 m. 17 c.

Then followed 38 m. lined with 8½ inch casing.
„ „ 28 m. 13 c. „ 7 „
„ „ 29 m. 15 c. „ 7 „

The bore-hole had now reached a total depth of 388 yards, and as no signs of change of ground were perceptible, it became clear that it would have to be put down to a considerable depth. The last five strings of casing had averaged 102 feet, and had lost 5 inches in diameter over a depth of 170 yards, or at the rate of 1 inch per string. The diameter of the bore-hole was now 7 inches, and taking 4 inches as the smallest working diameter, there remained 3 inches for casing, or 3 strings of 31 m., say 93 m. This was not considered enough depth, and the author then determined to continue the boring with lap-welded artesian casing with screw joints. Accordingly a string of 6-inch casing was put down, extending from the top, and the boring continued with a rimer or undercutter giving a diameter of hole 6 inches. This casing was securely fastened at the top, and when sufficient ground had been undercut, one and sometimes two pipes of 5 metres length were screwed on at the top and the whole length let down by means of a set of strong pulley blocks. The boring was successfully carried on by this process to a depth of 435 m. 95 c., when an accident occurred which interrupted further progress.

On the 2nd October, 1890, in moving the artesian casing in order to add a length at the top, the screw of the third pipe from the surface slipped, and the whole string of casing dropped to the bottom; every effort was made to raise it, without success, and the author then determined to continue the boring from the depth of 436 m. 95 c., now cased with 6-inch casing, by running a string of 5-inch artesian casing inside the 6-inch casing. This was accordingly done, and the hole was successfully carried down to a depth of 613 m. 15 c. The 5-inch casing had been lowered to a depth of 581 m. 49 c.—that is 144 m. 14 c. below the 6-inch casing; at this point, in trying to lower the 5-inch casing, it was found that it was held fast by the swelling clay. Under the circumstances it would have been necessary, in order to continue the boring, to put in a third string of artesian casing 4-inch diameter, and as this would have been the last string under any circumstances, sheet iron might have been used. The former would have secured a further depth of 150 m., the latter probably 80 m. to 100. In either case a new set of smaller tools would have been necessary, and under the circumstances, considering the great depth already reached without any decided change in the ground, it was determined to stop further drilling as the discovery of the coal at such great depth would not have been of compensating value.

As soon as it was determined to stop the drilling, arrangements were made to draw the casing out of the bore-hole. On the 11th April, 1891, this work was commenced. The casing had now been standing in the bole-hole for 5 weeks, and it was to be expected, would be tightly jammed by the clay; therefore every precaution had to be taken. It was soon found that the fall blocks were insufficient to move the casing and a pair of jacks had to be applied. By this means the first pipe of the 5-inch artesian casing was raised inch by inch out of the bore-hole. The next 87 pipes were raised by the pulley blocks, and the remainder hanging quite free in the 6-inch casing, were raised by the rope and drum of the rig. The 6-inch casing which had run down was caught again by letting down a length of three pipes and screwing them on from the surface. But on attempting to raise them the screw slipped again, and only the three upper pipes were raised. An attempt was then made to raise the casing by letting down an expanding tool made of steel and intended to secure the casing by cutting into it. But the casing was so jammed by the swelling clay, that the instrument, on being drawn up, ripped through the wrought iron casing and came up damaged itself, but without moving the casing.

The boring was commenced on the 29th September, 1889, and stopped on the 20th March 1891, at a depth of 613 m. 15 c., equal to 2011 feet, having occupied 1 year 5 months and 5 days. During this period several delays occurred, such as waiting for tools and casing, a few accidents intervened, and in the early part of 1890 the fire-box of the boiler gave way and had to be repaired, which caused a delay of six weeks. Taking the time occupied in completing the boring, namely 520 days, the average sinking amounts to 3 feet 10½ inches per day.

Eliminating the stoppages, and taking the time of effective working, namely 265 days and 12 hours, the drilling amounts to 7 feet 9 inches per day. These 265½ working days were employed as follows:—

	days	hours
Drilling	190	8¾
Using the sand pump	42	2¾
Putting in casing	9	1
Fishing up broken tools	8	3¼
Small repairs to engine and rig	15	20¼
	265	12

The actual drilling averages 10 feet 6 inches for 24 hours. The greatest distances drilled in one day were: 22 feet 4 inches at a depth of 174 feet; 20 feet 4 inches at 300 feet; 22 feet at 1883 feet, and 21 feet at a depth of 1922 feet. The bore-hole was perfectly straight, and ended at the total depth of 2011 feet, with an internal diameter of 4½ inches. The point of interest attached to this boring is the great thickness of clay which has been passed through. The mere depth is not very considerable as compared with many other bore-holes put down in recent years, but the author is not aware of any bore-hole which has been put down through over 2000 feet of swelling and adhesive clay. At times the chisel stuck so fast in the bottom that it took all the power of the engine to drag it out, and frequently the rods broke. On two occasions the chain gave way, and some conception of the strain may be formed from the fact that it was made of 1-inch iron. When the chisel stuck, and the full power of the engine was applied, the whole rig oscillated about like a ship at sea, yet no serious accident occurred during the process of boring, and it is a great point in favour of the Canadian system, that this, which may be considered a difficult boring, was successfully carried out by that method.

It may be interesting to state that inflammable gas was first observed at a depth of 702 feet, and from that depth onwards became more abundant as the boring proceeded. When drilling was not going on, the noise of the bubbling gas in the bore-hole was like the boiling of a gigantic cauldron. A strong fresh-water spring was struck at 960 feet, and a little lower down, at 1010 feet, a spring strongly charged with salts, mostly chloride of sodium, but also some bromide and iodide. The quantity of these valuable salts contained in the brine from the tegel is about 1·50 grammes per 10,000 grammes of water. A similar spring of iodide and bromide salts was found in the boring previously referred to, and after the explosion which stopped the sinking, this spring was profitably applied. In winter the brine is pumped up and evaporated to dryness, and in summer it is used for baths and drinking in a bathing establishment erected for the purpose, in the vicinity. The cost of this bore-hole can only be approximately given. It amounted to over 2*l.* per foot. The work was not carried out by contract, and the cost includes the purchase of the tools, casing and machinery, less the amount realised by their sale at the end of the work.

In conclusion, the author would observe that taking one consideration with another the Canadian system of drilling has many advantages. In ground where the strata are much inclined it is preferable to the rope system, because it is difficult to keep the hole perpendicular by the latter method. By the use of the jars a much greater rapidity of drilling is secured than with the free-fall tool. Lastly, in soft ground it is possible to bore and obtain a section which could not be done with the diamond crown. The latter is admirably adapted for drilling through hard ground when a core can be secured, but in softer measures it is not reliable as indicating the nature of the strata, and it is well known that even a seam of coal may be passed through with the diamond drill and not be recorded in any way. The Canadian method of boring has hitherto been almost exclusively applied to petroleum wells in easy ground, but it can be used for deep bore-holes through difficult ground, as may be seen from this boring successfully carried down upwards of 2000 feet through nothing but clay.

DISCUSSION.

The PRESIDENT said he was sure it would be the desire of the Members to pass a cordial vote of thanks to Mr. Boyd for his valuable and, to some extent, historic paper, which was doubly valuable because it was the first on the subject that had been read before the Society. There were a few questions which he should like to put to the author. The first referred to the height of the fall of the tools. Was the maximum only 2 feet 6 inches? It seemed a small one to develop sufficient energy to do the required work. Again, what was the weight of the tools and the duty of the blow struck by them? At the first glance it did not appear that the energy was as great as might be expected. With regard to rotating the tools when at the bottom of a deep boring, of course it was impossible to effect that when simply a rope was used to support them; and he should like the author to explain how the turning was effected and also in the case where solid rods were used. The weight of the tools when a great depth must be very considerable, and it would be interesting to know what mechanical arrangements were employed, or were the tools turned simply by muscular power? The author had referred to some casing tubes only $\frac{1}{8}$ inch thick, but he (the President) was of opinion that the rivet heads would foul the tools as they were lowered or raised. A thickness of $\frac{1}{8}$ inch was too little to allow of the use of countersunk rivets. With reference to the breaking of the rods, did they break through the constant concussion causing molecular alteration in the structure of the iron and steel, by what was known as "fatigue," or did they fail by tension when being pulled up? Were the rods of iron or of steel, and what was the quality of the material? Lastly, was any record kept of the temperature of the ground as the borings progressed—say for every 100 feet?

The vote of thanks was accorded unanimously.

Mr. G. STOCKFLETH said that the deep boring of 2000 feet had been done through clay from top to bottom, and that was the most difficult ground to cope with, not excepting rock. The excellent result of that particular drilling was probably the reason why the author had said more in favour of the Canadian system than he (Mr. Stockfleth) should say. He did not agree with the author's statement that by means of the Canadian system it would be possible to bore a hole straighter than by the rope system. On looking at the diagrams showing the two strings of tools on the two systems it would be seen that the American string consisted first of the temper screw hung up in the walking beam; then came the rope; then the sinker bar, the jar, the auger stem and finally the bit. The last parts of the string represented a very considerable weight, sometimes even more than the one ton which the author mentioned. In the Canadian system there was a long string of poles instead of the rope and sinker bar, connected together by iron appliances which made the string very heavy. Consequently at the end the tools could not be so heavy as in the American system. Therefore the centre of gravity of the American string of tools lay much lower than in the Canadian system. The American tools were therefore more certain to fall vertically and make the boring straight than the Canadian tools were. That was one reason why the American system was likely to make a truer hole than the Canadian. Another thing was that at a depth of 2000 or 3000 feet, or even more, the driller was working under unfavourable conditions. As he could not see his work, he must be able to feel; it must be made as easy as possible for him to do so. With the Canadian string that was not done. The string of poles would scrape against the side of the casing, and the driller would not be in a position to know what the tools were doing. But with a rope which was only 1¾ inch for a 2000-feet hole, and which was kept perfectly straight within the casing by the sinker bar, there could be no question of rubbing against the sides, consequently the man could feel what the tools were doing. This would prevent his going on for a long time making an incorrect hole.

As regarded the casing in the boring described in the paper, an 18½-inch casing was used to start with, and as many as 11 different sizes of casing had been used. That was over the average, although the adhesion of the clay must be taken into account. The clay would suck itself so close to the casing that very often it was difficult to move it. However, the author stated that the casing had been put down with the help of the walking beam. He did not think that that was the most practical and efficient way of putting it down. If it was jammed with a wooden ram hung up in the sandline and with heavy iron clamps on it, the casing would usually be forced down more easily. Another point was that if in lowering the string of casing in clay the work was stopped say every night, it might be impossible to move the casing again the next morning; but if it was kept going with a few hours' interval it could be forced down to a considerable depth. He had obtained his experience not only from drilling, but from driving piles for foundations. In the main he thought that for deep drilling the American system was to be preferred, being much quicker and less liable to accidents than the Canadian.

Mr. GEORGE ADAMS said he had had a little experience in drilling for petroleum. He thought Mr. Stockfleth had made a mistake in speaking of the two systems of drilling. The American system was all very well when the strata were perfectly horizontal: in that case they could be easily penetrated; but if the strata were at all inclined the chisel fell off, and there was great difficulty in keeping the hole straight. He thought the greatest proof of the efficiency of the Canadian system was that it was in use nearly all over the world, with the exception of the United States.

Mr. R. J. B. SHARPE asked whether blasting by means of dynamite cartridges was resorted too in well-boring. Of course it could only be done in boring for water, and not in boring for petroleum or coal. On a section of the Manchester Ship Canal he was boring for water, and one of the men dropped a small chisel down across the hole, and the borers could not cut through it. A small charge of dynamite was used, however, and cleared the obstruction.

Mr. W. G. PEIRCE said that about two years back a well was bored at Gatti's restaurant in the Strand by Messrs. Mather and Platt's apparatus, and he was informed that it was one of the best machines for boring a deep hole. Some time previously to that, some friends of his watched a boring with it for water in the north of England, and they were puzzled to know how it was that it was so superior to another machine which they had in use. They afterwards found it was because there was a link just above the chisel which caused a second blow to be given to the tool. After the tool had dropped by its own weight on the bottom of the hole, the rod above the chisel jumped down in the link, doing the work of a hammer. Another great advantage in the machine was that the tools were made almost flat. There was very little cutting edge, and the tool had a pulverising action on the rock which made it very successful. He had had no experience with the other boring chisels referred to in the paper. At the Richmond Water-works 1446 feet of boring had been done, and they had had four contractors on the undertaking during the past 18 years. They had used the old system of boring with rods by Messrs. Baker and Sons, which answered fairly well with the flat single tool, but the chisel cut the rock earth in grooves, and did not make a perfectly round hole. Another firm of contractors, Messrs. Mather and Platt, used the rope-boring machine with boring head and several chisels. One great advantage of that method of boring was that they could lower the tool and bring it up very quickly. The Mather and Platt machine did a large amount of work through chalk and clay in a very little time. After it got down into the sandstone rock, a change was made, and Messrs. J. Docwra and Sons' diamond rock-boring machine was brought into use. That was a magnificent machine for cutting through hard rocks, and it finished the boring down to the depth of 1446 feet. Messrs. E. Timmius and Sons bored another hole, by means of the old-fashioned rods, but those contractors had now introduced the American rig, and they did almost all their boring work with it. He should like to know the largest diameter that had been bored by the American machine.

In the Richmond well the temperature at 1446 feet was reported to be 72° Fahr. With regard to the blasting of bore-holes, he would give his experience with the use of explosives at Richmond. He had used both dynamite and gelignite. The last explosion was carried out on December 13, 1890, with 10 lb. in each of four bore-holes in the adits, and 20 lb. of gelignite at a depth of 470 feet from the surface under a 245 head of water, the bore-hole being 11 inches in diameter. The explosion shook the whole of Richmond Hill. Unfortunately the blast was unsuccessful. Messrs. J. Taylor and Sons exploded a series of charges of roburite in a boring at the Herne Bay Water-works with great success, a large supply of water having been obtained by that means.

Mr. W. H. Holttum said he hoped the author would be good enough to enlarge somewhat upon the question of keeping the holes straight when boring at great depths, more especially as a previous speaker had alluded to the American rope system as being better in that respect than the Canadian system. It was very difficult to realise that that should be the case, but he (Mr. Holttum) had had no experience of either system. It had been said that the centre of gravity being lower in the American system caused the tool to give a truer and steadier blow. He did not know what the length of the tool was.

Mr. Stockfleth said it was from 20 to 60 feet.

Mr. Holttum said he was not aware that it was so long. Efficiency was attained by prolonging it. It was a common thing in England in boring to have a tool 50 feet long. By drawing it up and down they could ensure straightness. He should be rather inclined towards the system which had a length of 60 feet. The lining of the bore-hole was rather thin, and would very soon wear out under any circumstances; but still there were ordinary methods of keeping the working rods from injuring it. He should like to know why the author did not use either thicker tubes or tubes of steel. The steel pipes could be thoroughly driven, but thin wrought-iron pipes would stand but little driving. He thought that the latter were almost obsolete in England. They had been told that the pipes had been ripped up in being withdrawn. That was a very natural thing. He thought that the lining of a hole with thin iron pipes was a mistake. It had been said in the discussion that a certain form of chisel gave a series of vertical scratches. Why had not a winged chisel been used? The wings of the chisel might be made quite wide enough to overcome any such objection. The winged chisel was always available in any well-assorted set of boring tools.

Mr. Peirce said that there was a short wing on the chisel to which he had referred, but it did not turn round properly at that depth.

Mr. Holttum said, with regard to the use of explosives, that there were many instances of their adoption when boring for water, but the explosion generally resulted in forcing the detritus at the bottom into the natural fissures of the rock whence the water was expected, and thus effectually choking them up. Boring operations should necessarily follow through the zone where the explosion may have shaken the rock below the bottom of the bore-hole.

Mr. J. W. WILSON, jun., said the remarks which had been made by previous speakers as to the sheet-iron linings were much to the point. He would like to know how much the inner tube had to be reduced in diameter in comparison with the one immediately outside it, in consequence of the rivets employed. It would also be useful if the author would give the comparative prices of the two systems of lining under discussion. The probability was that the question was simply one of price; and the cheaper system was seldom the more perfect. A previous speaker had suggested a four-winged tool in preference to an ordinary chisel. He (Mr. Wilson) had had something to do with a four-winged tool in a boring of moderate depth and he had found a great difference in favour of it. Towards the close of the paper the author referred to the cost of the bore-hole which he had been describing, and said that it could only be given approximately as amounting to over 2*l*. per foot. The reason was that the work was not carried out by contract. The apparatus was first purchased and then sold with such of the casing as could be withdrawn. He would ask what would be the probable price of such a piece of work if it was done by contract. The author stated that the work was given up because it was determined to stop further boring, as the discovery of coal at such a great depth would not be of compensating value. The question of the depth at which it was advisable to look for coal was coming before the world more and more every year, and the author was an authority upon the subject. Probably he would be able to tell them that the time was coming when coal would have to be procured, as a matter of necessity, at a considerably greater depth than 2000 feet. It would be remembered that that was one of the points upon which Mr. Price Williams and other speakers enlarged in the discussion which followed the author's interesting paper of last year.

Mr. H. O'CONNOR asked if the author could give the size of the largest hole that had ever been drilled, or the diameter of the largest tubes which had been used in the class of work referred to by him. He (the speaker) was anxious to try whether he could not remove the earth from a tube of something like 2-foot 6-inch diameter for the purpose of sinking foundations. He should therefore like to know by what method it was usual to remove the earth from such a tube as the one shown by the author of 18-inch diameter; whether by means of a miser or what? It might be interesting to note that in India, when the natives were drilling holes for blasting rocks, they used a round bar of iron with steel ends shaped like a chisel, the cutting end of the chisel being slightly wider than the bar. They jammed it in by hand, two men sometimes working together. They twisted the chisel round each time they got it down. It was something similar to the work done by the machinery illustrated, but it was not done with such power as the arrangement shown by the author would give.

Mr. Wm. H. Booth said that in a boring made in this country by the firm with which he was connected, the work was started practically with a diameter of 6 inches, and it went down to 1243 feet. A large portion of the boring was through the gault clay which closed in in a very remarkable manner and was the chief obstacle to the progress of the pipes. Sheet-iron pipes should not be allowed for the lining of any bore-holes for water. They could not be driven tightly into the rock, nor could they ensure the shutting out of impure surface water. As to the boring of holes perfectly circular by means of a T-shaped chisel with a single wing, a hole could be bored as true with that as with any other drill.

Mr. Perry F. Nursey said he thought Mr. Holttum was mistaken in supposing than an explosion in a bore-hole tended to stop up the fissures of the chalk. He believed that wherever fissures existed and had been sought for by blasting they had been opened out. The action of the explosive was undoubtedly to absolutely disintegrate the ground for a very large area around the centre of explosion. The more powerful the explosive the more ground was disintegrated. It might be thought that in chalk the pulverised soil would be forced into the fissures as Mr. Holttum suggested, but he (Mr. Nursey) did not think that was by any means the action. Indeed, he thought that it was disproved by the fact that in practice fissures had been opened up wherever they existed, and that a large accession of water had followed where blasting had taken place in chalk. Should, however, the pulverised chalk be driven into the fissures, the stoppage would only be temporary as the pressure of the water would dislodge the finely divided obstructive which would be in the form of a paste. Mr. Peirce certainly had a narrow escape of removing Richmond Hill when he used the enormous quantity of 24 lb. of explosives for one blast. In the case of a bore-hole at Ealing 470 feet deep, which he (Mr. Nursey) chambered by blasting under 350 feet head of water, he used only 2 lb. of carbo-dynamite, and for two or three days the men were pumping up simply chalk and water. That would give an idea of the amount of chalk which 2 lb. would disintegrate, and indicated what an enormous amount Mr. Peirce must have removed. In the case of the Ealing bore-hole the flow of water was only increased by about 15 per cent., but that was accounted for by the fact that the chalk upon which he operated was known to be a very hard non-waterbearing stratum, and blasting was only resorted to in the forlorn hope that fissures might exist in the vicinity of the bore and be opened up.

The PRESIDENT said that Mr. Booth had spoken about the bar having a T-shaped cutter at the end. Was one of the edges made to the arc of a circle?

Mr. BOOTH said that it was like an ordinary flat chisel with a segmental piece upon one side. On one edge, a small distance up, was a wing. The hole made by the chisel was perfectly circular. He had never known a good driller fail to make a good hole with it.

Mr. ADAMS said he had seen similar chisels in use on the Continent.

Mr. E. H. G. BREWSTER said that Mr. Boyd had spoken of the size of the engine which he had used and stated that it had a 10½-inch diameter cylinder, but he had not given the stroke nor the pressure of steam used, without which the information given would not be of much value. He then asked the author what depth he originally intended to bore to, and for what weight of rod he had provided, when he selected the engine. With regard to tools about which something had been said during the discussion, he (the speaker) thought it would perhaps be of interest to some if he described one that was not common and that had proved very successful. The tool was an improved form of shell pump; the improvement consisting of the insertion of a piston into the pump, which piston was worked by means of a rod that passed through the head of the cylinder. To the upper end of the rod was attached a small wire rope; at the lower end of the cylinder was the usual flap valve. In operation the piston was pushed down to the bottom of the cylinder so that it rested just above the upper side of the valve. The cylinder and piston were then lowered to the bottom of the bore-hole, and the wire rope attached to the piston rod was hauled up until the piston had been lifted to the top of the cylinder. That having been done, the cylinder and the piston were both raised to the surface. The inrush caused by the sucking action of the piston was found to have a very beneficial effect in clearing the bore-hole of the material to be raised and in filling the sand pump.

Mr. R. NELSON BOYD, in reply, dealing first with the question put by the President as to the weight of the tools, said that the tools which he had used in working on the Canadian principle weighed 10 cwt. at the minimum, and 1 ton at the maximum. A ton was about the weight of the tools used in America for the rope system, and sometimes more. The action of the jars did not appear to be understood. A pair of jars was nothing more than a pair of links in a chain. When the tools came to the bottom of the hole, the upper link slid down. There was no drop. The weight of the tools was 10 cwt. for a shallow depth, or a ton for a set of tools for a greater depth. They struck with their entire weight on the bottom of the hole. The jars were taken up by the upper link. The turning of the tools round was an easy matter, because, when the tools came up to the top, there was a moment when, irrespective of the weight, the whole set of rods and tools, and everything else, could be turned round by means of a swivel at the top of the rods. A very small turn was quite sufficient. It was not necessary to turn the tool round at each stroke when the machine was going at from 60 to 70 strokes a minute.

Several speakers had referred to the sheet-iron lining of the walls. The best answer which he could give on that point was the following statement made in his paper:—"The experience of the author justifies him in condemning this mode of lining oil wells." It justified him in condemning that mode of lining, except in a temporary well made to explore ground. The reason that very light iron sheeting was used, in the instance mentioned in the paper, was that they had not quite anticipated the depth that they eventually arrived at, and, as the hole was a temporary one, it was a matter of economy to use sheet iron instead of cast iron or steel, or lap-welded tubes. In the case of water wells or oil wells of anything like a permanent character, lap-welded tubing, whatever it might cost, was preferable to cheap sheet iron. The price in Galicia was something like 4*s.* per foot for the riveted iron, and 12*s.* for the wrought iron. Notwithstanding the considerable difference, it was better to spend 12*s.* a foot, or even more, if the well was to be a permanent one for water or for oil. The rods which he used were the Canadian wooden rods. They broke very frequently, not through concussion, but in drawing up, because the clay had such an adhesive power on the tools and chisels at the bottom. The great difficulty was to get the chisels out of the clay. In the case of ordinary ground, the rods broke at the bottom, if they broke at all. The temperature of the water coming up from a thousand feet was always about 20° or 30° F. higher than the temperature on the surface.

He had now to answer Mr. Stockfleth; and he was very glad to meet with a gentleman who had taken the part of the American rope system so ably and so completely. At the same time, he (the author) thought that the Canadian system might still exist in spite of that gentleman's criticisms, and in spite of the praise which he had bestowed upon the American system. In the first place, they had been told that the weight in the rope system was at least 1 ton, and might possibly be more. He had to record, as against that, that in the Canadian system they could put 1 ton down at the end of the wooden poles, and he had seen as much as that put at the end in very deep borings. As to the American system enabling the driller to feel what was going on at the bottom better than by the other system, that was a subject upon which he was not competent to reply. He, however, fancied that the blow at the bottom of the bore-hole was transmitted to the chisel and carried to the end of the driller, quite as delicately through the ash pole of the Canadian system, as through the hemp rope of the American system.

Mr. STOCKFLETH said that that would apply to a large tube; but the point was the use of a 1-inch or 1½-inch rope in a 4-inch casing. In such circumstances they could get at the tools; but they could not come alongside a 3-inch pole in a 4-inch casing.

Mr. BOYD said that he quite agreed. Possibly they could get down to a less diameter with a rope than with poles. The American system had two advantages. One was that with it they could bore down to a very much smaller diameter. The second was that the drilling could be performed with much more rapidity than with the Canadian system. That was an advantage which his friend did not seem to have weighed, though he (the author) pointed it out in his paper.

Mr. STOCKFLETH said that he had seen tools drawn up from a 3000-feet well in twelve minutes. A pole string had to be unscrewed at every 15 feet or 20 feet.

Mr. BOYD, continuing, said that Mr. Stockfleth had stated that by the American system the drillers were able to keep the holes straight, but he (the author) had always understood that if the measures were at all inclined there was a slight difficulty, in spite of the guides, in getting a perfectly straight hole. Some deep holes were tried in Hungary and in Galicia, and it was invariably found that, where the strata were extremely contorted in consequence of the presence of a range of mountains, such as the Carpathians, the drilling was in strata at an angle of from 45 to 80 degrees, and the American rope system was unsuccessful. The Canadians had come over and, by the rearranging of the tools and making them somewhat heavier, they had been able to pierce down to a depth of 1600 feet in the district of Galicia. He had himself gone straight down to a depth of 1600 feet. He quite agreed with what Mr. Adams had said on that subject. There was more dependence on the Canadian system for securing a straight hole than upon the rope system.

As to cartridges, he had seen them used very frequently in boring on a very small scale. They had been used for removing broken tools, or boulders, or things of that kind, at the bottom of a well. Nitro-glycerine was used constantly in oil wells, both in America and in Canada.

With regard to the size of the largest tubes, there was no limit to that, but the largest diameter of wells that he had known was 3 feet. That was in the case of some wells sunk by Messrs. Kind and Chaudron. The diameter of the German well was 2 feet 6 inches. It was put down on the ordinary German system. The depth which could be reached depended upon the nature of the ground. Sometimes an enormous depth might be attained, and sometimes the holes would telescope in very quickly, according to circumstances. He did not see that there was any objection to beginning a hole of 4 feet diameter if the proper appliances were at hand. The only way of keeping the hole straight when working on either the American or the Canadian system, was by means of guides consisting of pieces of iron put 25 or 30 feet apart. That method answered even in the American system, except when the strata were inclined. A pair of guides would keep the hole straight in the Canadian system. In that case the diameter of the guides must be equal to the diameter of the hole. The length of the string of tools which he used in the sinking described in the paper was 42 feet.

As to the cost of sinking, he had sunk wells for oil in Galicia by the Canadian system at 16*s.* a foot, including tubing and everything else. On the other hand, he had found other wells cost 30*s.* a foot. The difference was due to the circumstances under which the work was carried out. In some places machinery and other facilities were on the spot without having to be paid for specially. Where three or four wells were to be made near one another, so that the same appliances could be used for all, the average cost was about 1*l.* a foot.

He had been somewhat taken to task for saying that the depth at which coal would have been found in the case which he referred to in the paper was so great that the coal would not be of compensating value. He could speak on that point with some accuracy. A yard sunk through the clay in Silesia cost 50*l.*, and the total expense would have been something very considerable. The coal would not have been worth winning at that cost. The removal of the material which was ground up by the chisel inside the tube, was always carried out by means of some appliance similar to that spoken of by Mr. Holttum, and commonly called a sand pump. It was not necessary to have a piston inside. Kind and Chaudron in their very wide holes did not use anything but the sand pump.

Mr. HOLTTUM said that the piston was the point.

Mr. BOYD said that a piston was not usual, but it had been used for a particular purpose. As to the use of explosives for wells, it was very interesting in connectian with petroleum mines, but otherwise it had no interest whatever. If the engineer wanted to blow out the bottom of a petroleum well, he could not do better than to put down, say, 20 or 30 gallons of nitro-glycerine, and have a long tube with a cap, and drop a piece of iron down, and keep out of the way. That would produce a large cavity at the bottom of the well. But for ordinary sinking, a mere dynamite cartridge was quite sufficient to remove anything which the chisel would not remove. The T chisel had been described, and he recollected having seen it used, not in the Canadian system, but in the free-fall system. Perhaps the gentleman who had spoken of that chisel referred to the free-fall system.

Mr. Booth: The ordinary system.

Mr. Boyd said he had never seen the T chisel used in Europe in the Canadian system. He was unable to inform Mr. Brewster what the pressure of steam was in the engine. He should think that 20 lb. of steam was quite sufficient when they were drilling; but when the rods were being drawn and when they stuck in the clay, he put on as much pressure as the boiler would stand. It would be very difficult to state the exact average: 60 lb. at least was wanted to bring up the tools. The use of an engine in drilling operations was a very costly business. It was not a question of what the steam cost, but of getting down. The more quickly they got down, the cheaper the bore-hole would be, even if they did use a few extra tons of coal. In drilling for petroleum, if there were a few wells open already, the cost of the steam would not be very great.

The sand pump which had been referred to was a form of pump which he knew, but it was not generally used. The usual way was to have a valve at the bottom, as he had stated, and below that a ring of steel. The valve opened upwards, and the mud came in. If the ropes were then drawn up quickly the valve closed, and the stuff that was in the pipe was got up.

The deepest hole which he had been able to discover was at Schladenbach, in Prussia. It was 5000 feet deep, and he believed it was the deepest in the world. He did not see why they should not go to a depth of 10,000, 20,000, or 30,000 feet and, if possible, catch some of the dormant heat which was supposed to be in the centre of the earth. What had been done in the last year or so was an enormous advance upon what used to be done in the way of boring. All that was wanted for going to the depths he had indicated was more strength of tools and more perfect apparatus.

Fig. 1.

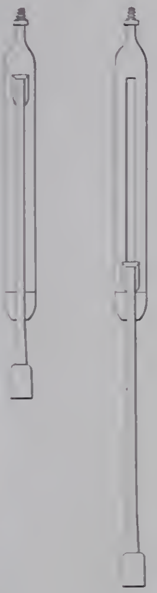


Fig. 2.

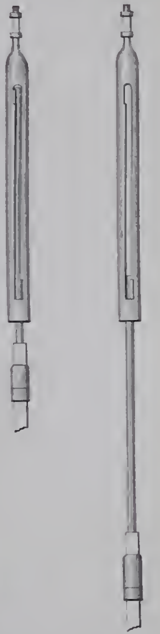


Fig. 3.

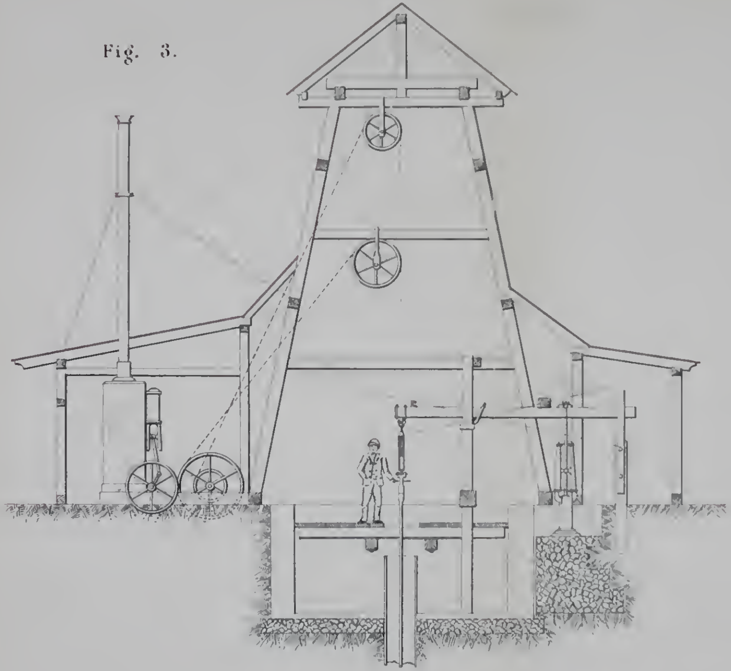


Fig. 4

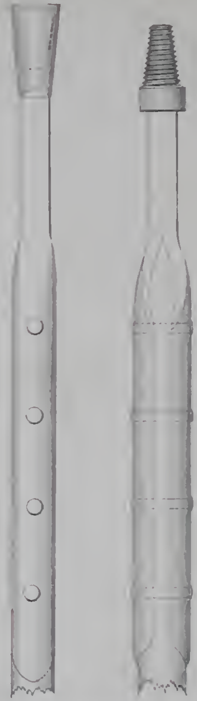


Fig. 5.

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Fig 6.
(Base)

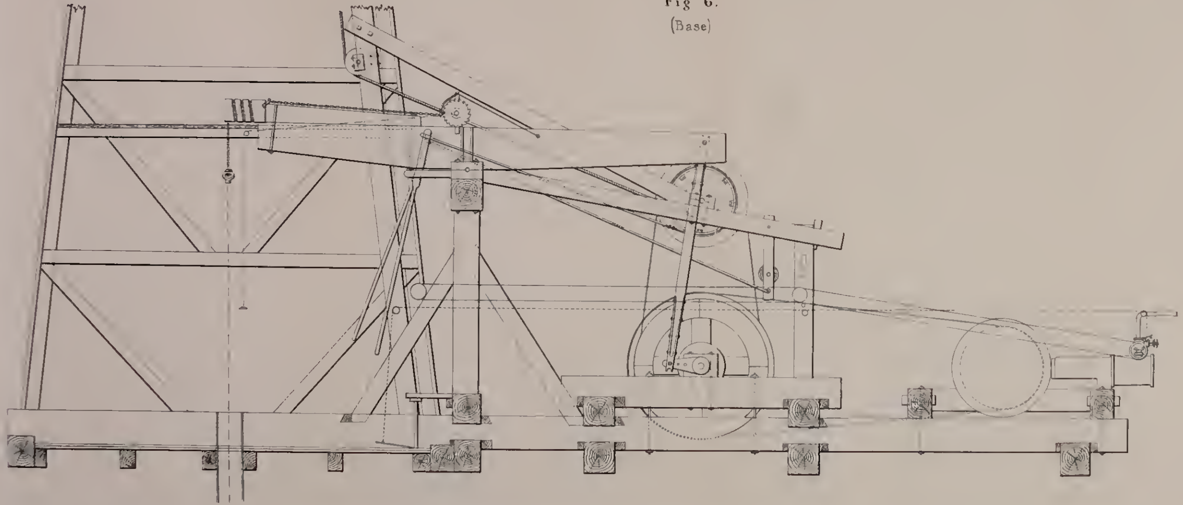


Fig. 6.
(Summit)

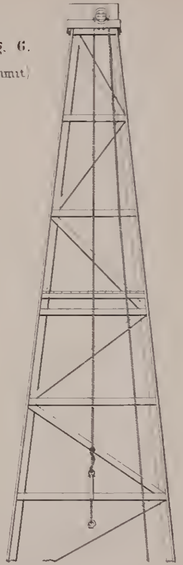
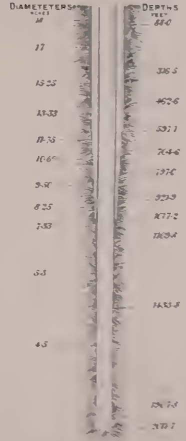


Fig. 7

FREISTADT BORING.



E. & F. N. Spon, London & New York

June 4th, 1894.

GEORGE A. GOODWIN, PRESIDENT,
IN THE CHAIR.

POWER DISTRIBUTION BY ELECTRICITY, WATER AND GAS.

BY EDWARD CARSTENSEN DE SEGUNDO.

FOR some time past the author has been struck by the great discrepancy between theory and practice that must exist in the working of electric generating plant in central supply stations where steam is used. Observation and experience alike have served to accentuate the inefficiency of electric generating plant, and some rough comparisons made with other modes of producing and distributing power have led him to go into the matter more carefully, and he is glad of an opportunity of bringing this matter before engineers for discussion. Such a subject as the distribution of power admits of practically endless elaboration. Moreover, nothing can be gained by generalisations from the results of existing or proposed distributing systems. The proper value of each system is entirely conditioned by the initial form in which energy is available, and by the final form in which it is required.

As one of the most important developments of modern engineering lies in the application of electrical energy to lighting, this latter will be considered as the final required form of energy, and coal will be taken as the initial form in which energy is available. These conditions apply to nearly all large towns.

In the present paper the author proposes briefly to consider:—

(1) The efficiency of electric generating plant in central stations at the present day.

(2) The efficiency of power-producing plant in hydraulic power stations.

(3) The efficiency of gas engines for the production of power.

The definitions of efficiency are probably more numerous, even, than those of load factor, and no doubt the ingenuity of that class of investigator which seeks to make a labour of investigation is not yet exhausted in the direction of finding out new possible ratios; but in such a paper as this, which is designed more to suggest a line for discussion than to deal with any discoveries or startling novelties, it is well to briefly consider which definition of efficiency is best calculated to serve the purpose of the paper.

The efficiency with which the practical engineer has to deal may be tersely expressed as the ratio of what you get to what you pay for. But while such a definition expresses the main value of a combination of machines commercially, it is not a convenient ratio for comparison with other similar ratios, because the introduction of market value at once destroys the possibility of bringing each fraction to a common denominator. As the motors that will be considered to-night are all heat machines, the author proposes to base his comparisons upon the ratio of the thermal equivalent of useful work available for commercial purposes to the calorific value of the fuel burnt per hour. Such considerations as the cost of fuel can easily be applied after.

This definition, however, is open to the objection that it is not fair. It may be argued that if a heat machine of necessity rejects a large proportion of the heat it receives, it is not just to calculate an estimate of efficiency upon a basis which is impossible of realisation, and that the efficiency should be expressed by the ratio of useful work to maximum possible useful work in that class of heat machine. The author would submit that while such a contention bears the semblance of justification, it should be borne in mind (1) that the fact of a machine necessarily rejecting a large proportion of the heat received cannot be pleaded as a valid reason why such a proportion of heat should be rendered unavailable; (2) that the definition adopted by the author gives an absolute basis for comparison; (3) that as long as the meaning attached to the word efficiency is quite clearly understood, it can make no difference to the argument if the actual, instead of the ratio of the actual to maximum theoretical efficiency is used; (4) that the latter is merely one of the very numerous definitions of efficiency.

A steam engine is usually accounted an extremely wasteful heat machine, but this is, strictly speaking, not the case. The only way to increase the efficiency of the steam engine is by lowering the lower limit of temperature, but directly efforts are made in this direction a limit is soon reached beyond which further lowering of the temperature not only ceases to be productive of any good, but is productive of evil. In short, it may be said that all the heat developed in the combustion of fuel is utilised by the steam engine, either in doing work or in providing the means of doing work or controlling the rate at which work is done. The efficiency of the steam engine and boiler combined is not difficult to determine; it is the ratio of the thermal value of the brake horse-power hour to the calorific value of the fuel consumed per brake horse-power hour.

The efficiency of the gas engine and its equivalent of steam boiler requires some investigation. A ton of coal, according to Mr. Emerson Dowson, may be taken to produce 9500 cubic feet of gas and 1500 pounds of coke, of which about 400 pounds will be consumed under the retort. Assuming that coal having a calorific value of 14,000 thermal units per pound is used, and taking the calorific value of coke at 10,000 thermal units, the number of thermal units liberated from the ton of coal is (neglecting heat necessary to raise the mass of coal to the temperature of the retort)

$$2240 \times 14{,}000 - 1500 \times 10{,}000 \text{ or } 16{,}360{,}000 \text{ thermal units.}$$

Of the heat developed by the consumption of the coke under the retort, a large proportion can never be expected to reappear in the gas. But 16,360,000 thermal units have actually disappeared in producing 9500 cubic feet of gas, hence $\frac{16{,}360{,}000}{9500}$, or 1722 thermal units, should be accounted for per cubic foot of gas.

Professor Kennedy, Professor Unwin and others have made calculations of the calorific value of a cubic foot of gas, the results of which agree fairly. The average calorific value of London gas may be taken as 620 thermal units per cubic foot at 55° Fahr., and at a pressure of 14·7 lb. per square inch, hence the efficiency of the gas generator is $\frac{620}{1722}$ = about 35 per cent.

The function of a steam boiler is, in the case of the gas engine, split up into two, one portion is done at the gas-works, and the remainder in the cylinder of the engine itself. Now about 24 per cent. of the heat given to a gas engine is turned into indicated power, or in the case of a large sized engine about 20 per cent. is converted into brake horse-power. Hence the real efficiency of the gas engine and boiler, so to speak, is about 7 per cent. The efficiency of a non-condensing steam engine consuming 2 lb. of coal of a calorific value of 14,500 thermal units and working at 80 per cent. mechanical efficiency, is 8·72 per cent., so that the total efficiency of one machine is very much the same as that of the other on this basis of argument. But Mr. Dowson claims to produce one brake horse-power hour for 1 lb. of anthracite, by using his generator gas. This (taking the calorific value of anthracite at 16,000 thermal units per pound) would correspond to a total efficiency of nearly 20 per cent., an efficiency which the steam engine and boiler can never hope to reach.

Although the author desires to consider the two heat machines on the basis of what may be termed the useful efficiency, namely, the ratio of available power or brake power to power equivalent of fuel burnt, still, in the face of so great a difference as the foregoing, it may be of interest to inquire into the reason of the difference, and to do this it is necessary to consider another efficiency, namely, the ratio of heat turned into work in the cylinder, to the maximum theoretically possible. This latter quality is expressed by Carnot's law as the ratio of the difference of temperature at which heat is received and rejected to the absolute temperature at which the heat is received. In the case of the steam engine this ratio is not difficult to determine, because the heat is all received at one temperature and rejected at one temperature. But in the case of the gas engine this is not so. As previously mentioned, part of the function of the boiler, or part of the operation of calling into existence the working fluid whereby heat energy may be transformed into mechanical energy, is performed in the cylinder of the engine itself. This operation cannot be instantaneous, in obedience to physical laws, therefore the heat is received during an appreciable interval of time and at temperatures varying from the temperature of the mixture and the end of compression to the maximum temperature reached by the charge after explosion. In some parts of the cylinder this temperature may, according to Mr. Clerk, be as high as 3400° Fahr. It would appear, however, that most authorities agree upon 2700 Fahr. as about the maximum temperature reached by the charge in gas engines of all forms. The temperature of the discharged products is not far short of 800° Fahr., though of course the heat rejected is not rejected at one temperature. Hence the maximum efficiency attainable should be $\frac{2700-800}{3160} = \frac{1900}{3160} = 60$ per cent.

The efficiency of the non-condensing steam engine cylinder under an admission pressure of 130 lb. per square inch and an exhaust pressure of 20 lb. per square inch would be about 18 per cent. Therefore, if this steam engine turns 8 per cent. of the heat into work, it is doing as well relatively to its peculiar limitations as the gas engine that turns 26 per cent of the total heat received into work. The greater useful efficiency of the gas engine, therefore, must be ascribed to the nature of the vehicle used for carrying the heat, and not to the superiority of the gas engine as a heat machine. The great faults of a gas engine are (1) the enormous heat lost in the cooling effects of the cylinder jackets (sometimes over 50 per cent. of the total heat), and (2) the high temperature of the exhaust products. It is not within the scope of this paper to even suggest any direction in which the efficiency of the gas engine might be enhanced, but it is obvious that if the link could be forged between the now disconnected heat chain in the gas engine cycle, whereby the heat carried away in keeping down the temperature of the cylinder could be usefully expended in some other part of the cycle, the time would not be far distant that Sir Frederick Bramwell has spoken of, when all that remains of the steam engine would be a working model or two in some obscure museum.

Let us now consider an electric generating plant using steam power. Tests of various portions of electric generating plant are continually being published which, if they are any criterion of what may be attained in practice, would point to an extremely high efficiency of a generating station as a whole. Any dynamo manufacturer would be much insulted if one were to suggest hat his 30 kilowatt machine would not yield a commercial efficiency of over 90 per cent. at anything like full load. The makers of high speed, non-compound, non-condensing engines claim a mechanical efficiency of something like 90 per cent. with a steam consumption of 18 lb. 1 h.p. hour, or 20 lb. per brake horse-power hour, and, moreover, they are always prepared to prove it.

Only a few weeks ago Messrs. Siemens published an account of a test of a steam dynamo driven by a Willans engine, which resulted in a combined efficiency of 88 per cent. It is also possible to obtain boilers which will evaporate over 12 lb. of water from, and at 212° Fahr., per pound of good coal. Now it may be interesting to compare the best possible results based upon such efficiencies. Take a pound of coal whose calorific value is, say, 14,500 thermal units. The author is given to understand that certain boilers in one of the electric generating tations in London evaporate 12·8 lb. of water from, and at 212° per pound of coal. This would correspond to an efficiency of about 75 per cent. Allowing 30 per cent. for loss in transmission and radiation, and 13 per cent. as the highest thermal fficiency of a non-condensing, high speed steam engine using 8 lb. of water per indicated horse-power hour, this would leave 372 thermal units turned into work in the cylinder of the ngine.

Taking 88 per cent. as the efficiency at which a steam dynamo was recently described to be capable of working, 1207 thermal units, or nearly 350 watt-hours, should reappear at the dynamo terminals, and subtracting 10 per cent. for loss in distribution, 315 watt-hours should be paid for by the consumer per pound of coal burnt at the station. This is equivalent to a consumption $\frac{1000}{350} = 2 \cdot 86$ lb. of coal per unit delivered. Were a full load to be maintained at a generating station, this result is what should be realised if the efficiencies claimed for the various factors are trustworthy. But nothing approaching this figure is attained in central station work, and the whole of the discrepancy is attributable to the influence of a load factor. In all, eight definitions have been given of the term load factor. In the considerations under review the author takes the following definition, namely, the ratio of total output to safe maximum output for which the plant is designed. It will be interesting to compare existing practice with the result obtained by assuming efficiencies, &c., which may be reasonably considered to accompany the working of a plant under the ordinary working conditions in England.

In a modern generating station the sizes of the generating units should be so proportioned, and the general arrangements so designed as to enable a careful man to keep the load on those of his units which are running at a minimum of from 50 to 60 per cent. of full load. This means that on the average, the units in work will run at something considerably over half load. From calculations based on the results of actual practice, the author has arrived at 9·5 per cent. as the ratio of thermal equivalent o watts at the dynamo terminals to heat contained in stean supplied which should obtain in a well-regulated central station under ordinary conditions of working in England.

Taking as before one pound of coal of a calorific value o 14,500 thermal units, allowing a boiler efficiency of 70 per cent. 10 per cent. stand-by losses, 9·5 per cent. efficiency of stean dynamo, and 10 per cent. loss in distribution, not more than abou 4·4 lb. of coal should be consumed per kilowatt-hour, delivere to consumer's terminals. But this figure is not approached i practice, except in one instance by Mr. R. E. Crompton, wh states that at Kensington Court he burns 5·5 lb. of coal pe kilowatt-hour delivered all the year round ; but he states tha in doing this he forces his boilers, although it is not easy t appreciate the exact meaning of forcing a boiler. Certainly forcing a boiler usually results in a greater evaporation at greater consumption per pound of water evaporated, as it is wel known that a boiler works most economically at about three quarter load.

Professor Kennedy has obtained some very good results in the generating station of the Westminster Electric Supply, but not approaching the figure above arrived at. Mr. Druitt Halpin stated, in the course of some remarks at Nottingham last year, that an analysis of the Board of Trade returns of electric light companies showed an evaporation per pound of coal of only 4 lb. of water in the best example and of one or less than one in the worst. This anomaly is difficult to account for, it is usually ascribed to a low load factor, but this hardly seems reasonable. Take for instance the working of a station of the London Hydraulic Power Company. The plant consists of boilers, engines and pumps combined, and accumulators which in practice only act as equalisers. The efficiency of the boilers, the stand-by losses, and the loss by radiation will be about the same as in the case of an electric generating plant—at least, there is no reason why they should be different. But the engines will probably be more economical because, although they run at a diminished speed where the demand on the mains is small, they always work at full load per revolution. Of course the engine efficiency is not quite so good at slow speed as at high, but even at a slow speed an engine working at full load per revolution must compare favourably with one doing the same total work in horse-power hours at double or three times the speed. Moreover, at a hydraulic power station it is generally practicable to use triple-expansion condensing engines.

As the thermal efficiency of steam engines, under such working conditions as obtained in central power producing stations, is extremely difficult to determine with any accuracy, it may be of interest to arrive at its figure by calculation of other efficiencies as nearly as they can be estimated. Probably 9 lb. of coal of calorific value of 14,500 thermal units per pound is not an excessive figure to assume as an average performance of London central electric stations per kilowatt-hour, paid for by the consumer. Now one kilowatt-hour is equal to about 3420 thermal units. Adding 11 per cent. for loss in distribution and allowing 1·25 as the counter efficiency of the dynamos, there should appear on the crank shaft of the engine, so to speak, the equivalent of about 4750 thermal units. But to effect this, 9 lb. of coal have been burnt, liberating $145 \cdot 00 \times 9 = 130{,}500$ thermal units, so that the efficiency or non-efficiency of working of boiler and engine together with attendant stand-by and radiation losses are responsible for 96·2 per cent. of the heat energy of the coal consumed.

Of course the engine and boiler, as heat machines, are not to be held accountable for the whole of this loss. It is mainly due to the conditions of working. But the question that naturally suggests itself under these circumstances is, is there no other and more efficient manner of generating and distributing light and power on an intermittent demand than by steam power, generating electrical energy and distributing it by means of copper mains?

It must not be forgotten that the coal consumption is by no means the only factor to be considered. Rents, rates and taxes, maintenances and distribution expenses, depreciation, management expenses and a host of other items have to be tacked on to the cost of coal consumed before the figure is reached from which profits can be calculated. But even on this basis the total for power delivered is strikingly smaller in the case of hydraulic power supply than in that of electric supply.

In a recent paper read before the Institution of Civil Engineers by Mr. E. B. Ellington, it was stated that the total cost per 1000 gallons delivered at 700 lb. per sq. inch was 12*s.* 6*d.* Now 1000 gallons at 700 lb. per sq. inch is equivalent to 8·34 horse-power hours or 6·25 kilowatt-hours nearly. There is no Electric Supply Company in London that delivers one kilowatt-hour at a less total cost than from 3·5 to 4½*d.* to itself. Thus the cost per equivalent of one kilowatt hour is rather more than double in the case of electric supply than in the case of hydraulic supply. The question is, as to whether this economy can be ascribed wholly to the superior economy of the steam engine in all hydraulic power stations, having regard to the fact, that not only is the hydraulic load curve similar in form to the electric load curve, but the load factors in both cases are similar. The author thinks not entirely, as a certain proportion of this economy must be due to the difference in the inevitable losses in the system of distribution and also to the difference in capital outlay for large powers.

In comparing distribution of power by high pressure water and by electricity, due consideration must be had to the purposes to which power is to be put. For working lifts, or cranes, or presses, it is doubtful whether any simpler and better means could be provided in a city like London, than water pressure. If on the other hand the form in which the power is delivered has to be changed before it can be applied, it is quite possible that the efficiency of transformation may be so low as to dissipate the economy attained in generation and distribution. Compare for instance, the number of transformations necessary to enable a lift to be worked and an incandescent lamp to be lighted from a central power-house.

LIFT.

Efficiency per cent.	Hydraulic Power.	Efficiency per cent.	Electric Power.
70	Boilers.	70	Boilers.
13	Compound condensing engines.	9	Non-condensing engines.
80	Pumps (including mechanical efficiency of engine).	80	Dynamos (including mechanical efficiency of engines).
99	Distributing system.	88	Distributing system.
		80	Motor.

Of the 14,500 thermal units liberated by one pound of coal, 1044 thermal units would reappear as useful work on the hydraulic system, and 478·5 thermal units on the electric system.

ELECTRIC LIGHTING.

Efficiency per cent.	Hydraulic Power.	Efficiency per cent.	Electric Power.
70	Boilers.	70	Boilers.
13	Compound condensing engines.	9	Non-condensing engines.
80	Pumps.	80	Dynamos.
99	Distributing system.	82	Distributing system.
66	Motor.		
90	Dynamos.		

On the hydraulic system about 620 thermal units should reappear in useful work, and on the electric system about 600 thermal units.

The foregoing assumptions are not made with regard to any particular load factor, but as the load factor is found to be very similar in public electric supply stations and public hydraulic supply stations, the conclusions indicated by the figures should not be materially altered. There is of course nothing very new about this result, but it is sufficiently striking to have induced a Belgian engineer of considerable reputation, the late M. Van Rysselbergh, to devote a large amount of time to the development of a system of hydraulic distribution in generating electrical energy which should enable electrical energy to be sold at considerably cheaper rates than at present.

It is unnecessary to discuss M. Van Rysselbergh's scheme in detail. It is evident that the only directions in which the efficiency of a system as a whole can be increased are (1) by decreasing the number of transformations of energy, and (2) by increasing the efficiency of either or all of these. Now the number of transformations of energy is not decreased but increased in the hydraulic system. The efficiency of boilers and dynamos cannot be very different in both systems. The difference in the cost of the distributing system is conditioned by circumstances. There remain then two efficiencies to be improved on, the efficiency of the engine and the efficiency of the distributing system.

The economy effected by a triple expansion condensing engine working as it does in an hydraulic power station at full load per stroke, over the steam engines forming part of the steam dynamos, now much used in electric generating stations, might well reach 50 per cent.; that is to say, where the steam engine of the steam dynamo gives 10 per cent., the triple compound as above might yield 15 per cent. The loss in a mile of hydraulic main, say 6·5 inches diameter, when transmitting 100 horse-power at 700 lb. per sq. inch at a velocity not exceeding 3 feet per second. would not greatly exceed 1 per cent., whereas the average loss in an electric distributing system rarely is less than 12 per cent., though doubtless this could be improved upon. Against these sources of economy must be placed the loss in the water motor, the loss in the extra transformation of motive power into electric light, and the loss in the low tension network surrounding each distributing station. Further, hydraulic mains have to be placed at a considerably lower level than the electric conduits need be for many reasons, and it can scarcely be even a matter of doubt that the total commercial efficiency of the whole hydro-electric system (by which is meant the useful efficiency modified by all such considerations as rents, rates and taxes, maintenance and depreciation, &c.) will compare unfavourably with the total commercial efficiency of direct electric supply.

There can be no doubt, however, that power can be produced and delivered hydraulically at a smaller cost than the electrical equivalent electrically. There must be a reason for this, and the reason is not far to seek. In the hydraulic power station a more efficient engine can generally be used; then this engine can be worked more efficiently owing to the fact that although the engine may vary in speed, it works always at full load to the stroke. There can be further a much greater efficiency in distribution through pipes. In hydraulic power supply the pressure is not a function of the speed of the pump (as in direct electric supply it is a function of the speed of the armature) but the pressure in the mains is maintained outside of the engine and pump, which only deliver enough water at a constant pressure to supply the demand on the mains.

At first sight it seems easy to apply this principle to electric supply by the introduction of an electric accumulator or storage battery to keep up the pressure on the mains. But unfortunately the analogy between a hydraulic and an electric accumulator is not quite complete: it breaks down in one important detail, namely, that while the hydraulic accumulator reacts in the same way upon both main and pump, the electric accumulator only acts in an analogous manner towards the main. Its effect upon the dynamo or electric pump is to drive the pump unless the pump is driven sufficiently quickly. What is wanted to complete the analogy, is the analogue of the non-return valve, and this so far has not been discovered. Moreover, while pressure can be exerted by a pump whose plunger is stationary, the pressure exerted by the electrical pump or dynamo is a function of the speed of rotation of the armature. Thus in order to supply a small demand, the steam engine of an electric generating station has to work at about 90 per cent. of the speed required to supply the full demand. There is no reason why an electrical generating station should not be able, provided the demand is sufficiently large and varied, to so apportion its generating units as to keep each unit in work loaded to 90 per cent. of its full load, in which case the only losses in the station would be 10 per cent. stand-by in boilers, radiation, &c. In the Berlin central station, where, owing to Continental habits of life, the demand is more favourably distributed over the 24 hours, such a condition is very nearly approached.

Now let us briefly consider how power produced by gas engines can meet the needs for electric light for a large town provided with a complete network of gas mains. In this case (which is practically the case of every large town in the civilised world) the electric light comes as competitor against the method of illumination which has practically only just established a firm reputation for reliability, economy, efficiency, &c. There is no doubt that the conveniences of gas for lighting and heating are apt to be overlooked because of our familiarity with them. Had we experienced the inconveniences of oil and candle lighting, the author feels sure the electric light would not have made so much progress as it has done. Further, the gas business is in the hands of a powerful body, powerful alike in experience and in resource.

Experience of practical working in London and other large towns shows that in certain districts and under certain conditions there is a sufficient demand for the electric light to make it worth while to work independently of the gas company altogether. But consider the vast majority of country towns already supplied with gas, where it is obvious that an independent electric light company would eke out a very miserable existence and that probably for only a short time; it would certainly seem reasonable that a combination of electric light and gas interests would solve the problem of electric supply to the inhabitants, and if this is so, then the principle ought to apply *a fortiori* to large towns. At present these interests conflict and it is universally experienced that some one has to pay for this conflict.

Let us try and examine this a little more closely. If electric light and gas interests harmonise, the first advantage that suggests itself is the ready made central station, namely the gas-works. It is then necessary to establish distributing stations at suitable points in the town. Each distributing station would consist of gas engines and dynamos and regulating apparatus. Each distributing station would supply its own network of mains for the needs of its own neighbourhood. These networks would have to be connected by a trunk main so that any one station could be relieved by any other in case of emergency and during the period of light load. The details of the plant of each station and the number of stations would be dictated by local conditions so that it is impossible to do more than state the broad principles. As there would be no boilers, no chimney stack would be required. Probably in nine cases out of ten the basement of some house could be adapted to accommodate the necessary plant, hence a great saving would be effected in special buildings. Further, the labour required would be diminished. The cost of superintendence would probably remain the same, but might be increased.

Now as to the cost per unit delivered. There is fortunately not much difficulty in determining this, as many examples of the generation of electrical energy by gas power now exist. The author has selected the results of the weekly records of a plant at Bradford, supplying 300 lamps. The total cost per kilowatt-hour delivered is almost exactly 2*d*., with town gas at 3*s*. 3*d*. per 1000. But to adapt this to a distributing station 5 per cent. should be added for loss in mains, and 0·3*d*. per kilowatt-hour for depreciation in plant and buildings. This would bring the cost to 2·4*d*. Adding the very liberal allowance of 0·6*d*. per kilowatt-hour for management expenses, the total cost would amount to 3*d*. per kilowatt-hour delivered. This is a lower figure than that usually realised in practice by any purely electric supply company working under the conditions above assumed, and no doubt this aspect of public electric supply has for some reason or other not received the attention it deserves.

In order that the two systems (direct use of gas and gaso-electric) be commercially equivalent, the cost of maintenance of the plant, the interest and depreciation and management expenses must be compensated for by the economy in gas consumed. Now it is frequently thought that nothing can be more economical than the system of sending the gas direct to the burner. But this is far from being true. The miserably low efficiency of gas burners is rarely appreciated. According to Professor Tyndall, the efficiency of the gas burner is 0·317 per cent. Taking the calorific value of London gas at 620 thermal units per cubic foot, only the equivalent of 10 thermal units reappear as light out of a possible 3100 thermal units in a 5-foot burner. When gas is utilised to produce motive power, its efficiency and that of the incandescent lamp is so superior that a very different result is obtained. The efficiency of a 16 per cent. incandescent lamp being about 6 per cent., and assuming a mechanical efficiency of 80 per cent. for the gas engines and 85 per cent. for the dynamos including loss in transmission, it is found that about 25 thermal units would reappear as light out of a possible 3100. So that in spite of the threefold transformation of energy introduced, the final result is increased 2·5 times. This ratio would of course be still further increased in the case of arc lamps. The value of these ratios, taking minimum values in the cases of electric generation by gas engine power, are as follows :—

Character of Burner.		Percentage increase of candle-power obtainable by using a gas engine to drive a dynamo supplying electric lamps, as compared with that obtained by burning the gas direct.
Gas.	Electricity.	
		per cent.
A good ordinary 5-foot gas burner, such as a Bengel burner.	An incandescent electric lamp, using 4 watts per candle, and giving 16 per cent.	78
A Wenham lamp	An arc electric lamp of same power as Wenham gas lamp.	227

The reason of this is that the chemical combustion of coal gas with oxygen yields a flame in which the undulatory vibrations of a sufficient frequency to become luminous are extremely few compared with the heat waves, whereas in a gas engine it is these heat waves that are transformed into mechanical energy.

The chief points of a gaso-electric system of distribution may be summed up as follows :—

1. The generating station already exists and may be considered as an eccentric power-house.

2. The existing gas mains are available, hence there is no

question of a separate main network being laid as in the case of hydro—or aero—electric supply.

3. The useful efficiency of gas is out of all proportion greater when utilised as a motive power than when burnt direct in burners, and this, in spite of the extra transformations of energy introduced.

4. It is more than probable that under a system such as has been discussed above, the cost of maintenance, superintendence and management expenses will be less than under conditions of independent electric supply.

5. By paving the way for the substitution of electric for gas lighting without conflict of existing interests, incalculable benefit being conferred on the community.

Of course the hydro-electric system may be treated from the same point of view if once hydraulic supply mains exist. But the present efficiency and character of high-pressure water motors do not suggest the possibility of any very great economy being effected. It must not be forgotten that Van Rysselbergh's claim to economy is based upon a motor efficiency of 80 per cent., which, though not unattainable, is very high and could not be relied on as an average result in practice. But for large private installations the energy supplied by the hydraulic power company could with advantage be utilised.

In conclusion, the author wishes to express his sense of the necessary incompleteness of the paper as compared with the title, but he hopes that the discussion may bring forward further points of interest he may have overlooked in the limited consideration given to the three branches of the subject which have been referred to, and trusts that the question of harmonious working of gas and electric light interests may also receive its share of consideration in the discussion.

DISCUSSION.

The President said that the subject of the paper was of great importance and the Society was much indebted to Mr. de Segundo for having brought the matter forward under the various heads into which he had divided it. The first point he would notice was what seemed to be a clerical error in the first part of the paper where it was stated that "The efficiency of the steam engine and boiler combined is not difficult to determine. It is the ratio of the thermal value of the brake horse-power hour to the calorific value of the fuel consumed per brake horse-power hour." It should have read "to the calorific value of the fuel consumed per hour" simply. Then another point to which he had to refer, was that in which the author quoted Mr. Emerson Dowson as having stated that a certain quantity of gas was produced per ton of coal. It was to be noted that that was the ordinary gas made at gas-works. The author referred to the efficiency of the gas engine as a heating machine. He (the President) would observe that he thought that the efficiency should be slightly higher than 24 per cent. He knew that 26 per cent. had been reached. Therefore the real efficiency of the gas engine and boiler would work out at 9·1 per cent. instead of 7 per cent. That was a closer approximation to the steam engine of 8·72 per cent. With reference to the great fault of a gas engine, viz. the enormous amount of heat lost, he might state that the average loss due to the cooling effect of the cylinder jackets was not so high as Mr. de Segundo gave, namely, 50 per cent. It would be found that the average was 35 per cent., while the loss in the exhausted gases was about 37 per cent. With regard to the load factor, some distinction ought to be drawn between the commercial load factor and the working load factor, because the commercial load factor took in everything that had to do with the working of the station, such as the stand-by losses, the cost of the attendants, and so forth. The working load factor should be considered when they wished to make comparisons between the working efficiency of different plants. If he might be allowed, he should like to refer to one statement which appeared in his Presidential Address: "This load factor is frequently taken as the proportion between the sum of work done by those engines at work during the hours they had been working, to that, that could have been done if all had been working at full load; but this was a method of reasoning rendered necessary by the use of a certain plant, for if, say, the units of motive power could be chosen as to agree or fairly approximate with the demand, being put in or out of action as desired, and that further, reservoirs from which the working fluid was drawn could be put in or out of action at once, then it would be seen that it would not be correct to say a load factor of 50 per cent. existed, because on the average only 50 per cent. of the engines were at work; for it might have so occurred that these engines at work were so, at their full and economical load. Of course this does not refer to a commercial load factor. Such a plant as described can be closely approximated to by a system of gas producers and engines; the former can be stopped or started by simply shutting off or admitting steam to the producer, and the latter could be increased or lessened as the exigencies of the work required. The waste due to the losses in fuel when the working fluid generators are at rest has been proved to be 10 per cent. in the case of steam boilers, and in the case of producers the loss is only about 5·5 lb. per hour for a 300 horse-power plant and when standing idle." One point to which he had not yet seen any reference made in the working of generating stations with a view to having a large available power to be called upon at will, and to reduce the stand-by losses, was the question of artificial draught, viz. forced or induced. He did not know that either of these had ever been used for these purposes. Forced draught and induced draught were somewhat similar in their results, but he would nevertheless very strongly recommend that suction draught should be used. When one considered that it was possible to increase the consumption of coal from the ordinary amount of 15 lb. per square foot of grate per hour up to 30 or 40 lb. at a minute's notice, it would be seen at once what a very ready and easy means existed of obtaining great power from the boilers at short notice. It was not always the case, as the author had said, that when the combustion of the fuel was increased there was a greater consumption of coal per lb. of water. In some experiments which he (the President) was aware of, where the weight of coal burnt per square foot of grate per hour was increased from 40·25 to nearly 43 lb., the actual evaporation of water per lb. of coal from and at 212° F. was also increased from 10·29 lb. to 10·48 lb.; and in another case where the consumption of coal was increased from 33·4 lb. to 4·55 lb. per square foot per hour, the evaporation of water per lb. of coal was increased from 10·63 lb. to 11·44 lb. Induced draught did away with the necessity for chimneys which were expensive and an eyesore, and perfect combustion with absence of smoke could be obtained.

He asked the author on behalf of the Society, if he could give some explanation as to the system of the Belgian engineer to whom he had referred for the development of hydraulic distribution for generating electrical energy. Messrs. Easton & Anderson had lately converted some hydraulic lifts which were originally worked directly from the Hydraulic Power Company's mains so as to work by electricity, and if any one from that firm was present the members would be pleased to hear him on the subject. The dynamo worked a pump, and the pump delivered the water into the accumulator, the accumulator working the lift in the ordinary way. He believed that the method was economical and he mentioned it as an example of what could be done by converting the power from one form into another. The author had stated that in a hydraulic power station a more efficient engine could generally be used and that it could be worked more economically than one in an electrical power station. He (the President) did not agree with that statement. He would now ask the meeting to accord a vote of thanks to the author for having brought the subject of power distribution before the Society in his very interesting communication.

The vote was carried by acclamation.

Mr. J. E. DOWSON said that in dealing with the efficiency of an individual engine, he agreed with the author that it was well, and in fact necessary, to compare the amount of heat energy in the fuel which was converted into work; but he also thought that in considering which system of motive power to adopt, they would get but a one-sided idea of the result if they limited themselves to the question of heat efficiency only. The author remarked, "A steam engine is usually accounted an extremely wasteful heat machine, but this is, strictly speaking not the case." In commenting on that statement Mr. Donkin would, no doubt, correct him if he was wrong in what he might say about the steam engine, but in the first place he would remark that it was a mere statement on the part of the author, and that the latter did not support it either by facts or by argument. Against that opinion he would point out that Professor Kennedy and others had shown that the efficiency of the steam engine—that is the amount of heat energy in the fuel which it eventually converted into work—could not possibly be much over 30 per cent. In actual practice its efficiency ranged from 5 to 15 per cent., and if he might be allowed to say so, it wanted something more than a bare statement to gainsay such figures as those. In the case of the gas engine, Professor Kennedy had shown in his Royal Institution lecture that the possible efficiency was something over 80 per cent.—not 60 per cent. as stated in the paper—and he preferred to quote Professor Kennedy, as he was an acknowledged authority. That 80 per cent. could be compared with the possible 30 per cent. heat efficiency of the steam engine. In practice, the gas engine efficiency ranged from 20 to 30 per cent., and they might compare those results with the 5 to 15 per cent. of the steam engine. It was of course well to know the consumption of ordinary town gas per horse-power in a gas engine and the heat efficiency of that engine; but he failed to see the use of comparing the amount of heat energy in the fuel converted into gas and other products at the gas-works, with the amount of energy converted into work by an engine. The fact was that the coal at the gas-works yielded tar, which represented a large number of heat units, besides coke and other valuable by-products, as well as gas. It should also be remembered that the gas had given to it a high candle-power for lighting purposes, which considerably increased its cost but added comparatively little to its calorific value for engine purposes. He thought that pointed to the necessity of taking account of the saleable value of the gas, as well as of its calorific power. If they merely considered gas as a heat-giving agent, they might say that such a gas could be used, and probably with high efficiency, for heating a steam boiler. But every one knew that as a working system the cost would then be greatly in excess of what it would be in the ordinary way of firing. The author was of course right in stating that, as a machine for converting heat into work, the gas engine driven by town gas had a high efficiency, but surely the working cost should be taken into account also. No doubt gas power had many advantages, and when a good gas engine was driven by town gas one was almost tempted to say that the conditions of working were ideal. No ground space was required for a boiler, and there was no chimney. There was no boiler to clean and to repair, and there was no boiler insurance. There were no clinkers and ashes to remove, and there was no fireman to pay. The engine could be stopped or started at will, and last, but not least, there was a large storage of power in the gas-holder. The ideal conditions were, however, largely discounted when the price of gas was high, and the leading makers of gas engines stated frankly that when the price of town gas was over 3*s.* per thousand cubic feet it was more expensive to drive a gas engine of 14 horse-power nominal or upwards, with such gas, than to work a steam engine of the same power. The fuel in the form of town gas was then too dear, compared with the coal used for the boiler. That brought them to the consideration of generator gas, which could be made easily and as quickly as steam could be raised in the boiler, and it was also very much cheaper than the other kind of gas. For engine work, generator gas was made from anthracite or from coke; but in considering the efficiency of working with anthracite, the author had assumed that a pound of anthracite yielded 16,000 heat units; whereas he (Mr. Dowson) believed that it was usually taken as 14,000. He would be glad if the author would give his authority for the 16,000 heat units per lb. On the basis of 14,000 heat units per lb. of anthracite, the loss of heat energy in the process of making generator gas was about 20 per cent. In other words, the efficiency of the gas plant was, under the usual working conditions, about 80 per cent. A gas plant might be said to be to the gas engine what the boiler was to the steam engine, and they might compare the efficiency which he had just given for the gas plant with the efficiency of the boiler which Professor

Kennedy had told them only reached 80 per cent. in thoroughly good working and with real care, but was often enough as low as 50 per cent. in everyday working without care.

Mr. BRYAN DONKIN considered that the paper was very well thought out. In his opinion it would be an excellent plan to adopt a thermal unit standard for comparing different coals, instead of speaking of so many pounds consumed per unit of power. Any coals, English or foreign, could then be compared, their calorific value being known, that is their heating value, exclusive of the very variable percentage of ashes, clinkers, and all incombustible matter. That standard had been partly adopted in America. In the paper Mr. de Segundo stated that all the heat developed in the combustion of fuel was utilised in the steam engine. Steam engines, however, did not consume fuel, but water in the shape of steam. The author no doubt meant that, but the point was not made quite clear. The efficiency of a gas generator was put by the author at 95 per cent. He (the speaker) did not understand what type of gas generator was meant—whether one on the Dowson system or the generator used in ordinary gas-works. Further on the author said, "The real efficiency of the gas engine and boiler, so to speak, is 7 per cent." That was rather an awkward way of describing the efficiency of a motor and evaporator, and, in the speaker's opinion, was liable to be misunderstood, as one of the great advantages of the gas engine was that it did not require a steam boiler.

Mr. DE SEGUNDO explained that he should have said the equivalent of the boiler.

Mr. DONKIN said that in the experiments with generator gas engines, the consumption was given at 1 lb. of anthracite per unit of power. He thought Mr. Dowson would agree with him that in some trials a still smaller consumption had been recorded.

Mr. DOWSON observed that he would hardly say that as an average result per brake horse-power, except in engines of large size.

Mr. DONKIN, continuing, said the author had put the loss of gas engines in the cooling jacket at about 50 per cent. of total heat received. That was perhaps a little high. It varied very considerably in different gas engines, with the size and type of the engine, and the speed, &c., but he considered that the loss was generally nearer from 30 to 40 per cent., and about the same quantity of heat, viz. from 30 to 40 per cent., was carried off in the exhaust gases. That would leave some 20 per cent. useful thermal efficiency, which might be taken as the average. The 26 per cent. mentioned by the President was exceptionally high.

He (the speaker) had had some experience with steam engine tests, and he thought that the mechanical efficiency of first-class motors might be taken generally at from 85 to 90 per cent. With regard to boiler evaporation or the number of pounds of water evaporated per pound of coal, he quite agreed with the author that with a good boiler and the best coal an evaporation of about 12 lb. had been verified during tests from 212° F. temp. of feed water, and he had sometimes obtained it himself. But to reach such a good result and to have dry steam, the boiler must not be forced. The author had very properly raised the question of forcing boilers, or, in other words, what forcing a boiler meant. He (Mr. Donkin) considered that the best way of defining the limits of forcing would be to give the number of pounds of water evaporated per square foot of heating surface. With regard to thermal efficiency, with the best boilers and under the best conditions he had obtained from 75 to 80 per cent.; 80 per cent. was about the maximum. In other words, 80 per cent. of the total heat in the fuel was usefully employed in evaporating the water. That efficiency sometimes fell to 50 per cent.

With regard to priming, it was of little use in boiler tests to give the number of pounds of water evaporated per pound of fuel, without knowing the percentage of water in the steam.

Mr. de Segundo said he assumed the steam to be dry.

Mr. Donkin, continuing, said that it seemed to him that to obtain the maximum economy in a steam boiler, the smoke should be allowed to escape at a temperature only a little above that of the steam. He had known that to occur in some economical cases. In experiments he had made on some of the London Hydraulic Power Company's triple pumping steam engines, he had obtained a thermal efficiency of about 14 per cent. for the engine alone during a ten hours' trial. Of course, during a test extending over several days or a week, that efficiency would be considerably less. The most interesting part of the paper was, he thought, the comparison between gas and steam motors. He had also been struck with the author's attempt to combine gas with electric interests. It seemed to him to require working out in detail, but it was well worth consideration. In some towns in Switzerland they adopted the plan of selling gas from the same mains at a much cheaper rate during daylight than at night. Gas was supplied for power, heating and cooking at a cheaper rate during the day, and better gas at a dearer rate for lighting during the night. It seemed an excellent plan, and might perhaps be adopted with advantage in some of the smaller towns in this country. Mr. de Segundo quoted Professor Tyndall's figure of 0·31 per cent. for the efficiency of a gas burner, but he did not mention the name or type of the gas burner or make any reference to Professor Tyndall's experiments.

Mr. F. Mead said they were all of one opinion as to the practical value of Mr. de Segundo's paper. The author had begun excellently by dividing his subject into three heads; and it would have been a great assistance to those who read the paper if he had bracketed together all he wished to say under each of the three heads, and drawn the conclusions at the end. There were various clauses in the paper which presented some little difficulty to the reader. One was the following: "The efficiency with which the practical engineer has to deal may be expressed tersely as the ratio of what you get to what you pay for." If they purchased an electric current, for instance, they purchased it with a large amount of the theoretical efficiency of the coal already knocked out of it; therefore, as electric current was "paid for" the definition did not seem to convey any precise meaning. The same remark applied to one or two of the other definitions set forth in the paper. The author went on to say, "The introduction of market value at once destroys the possibility of bringing each fraction to a common denominator." But the question of market value must be brought in where commercial considerations obtain, as is immediately afterwards proposed by the author.

With regard to the heat machines, the author said, "The fact of a machine necessarily rejecting a large proportion of the heat received cannot be pleaded as a valid reason why such a proportion of heat should be rendered unavailable." That was true, but it was a very valid reason for turning out the machine and using a more efficient one, if such could be procured and applied. Respecting the value of a ton of coal when converted into gas for use in a gas engine, a previous speaker had called attention to the fact that, although the thermal value of the coal was taken at 14,000 in one place, 14,500 was taken in all other places. In the clause under consideration the whole value of the coal was taken. From that was deducted the value of the coke left in the gas retort, but no deduction was made for the tar, which had really a high thermal value. If all was taken into consideration, the result of 35 per cent. quoted by the author as the efficiency of a gas generator would be materially affected. It would be nearer 43 per cent. than 35 per cent.

Respecting the use of hydraulic power for the purpose of driving a motor and dynamo, he observed that Mr. de Segundo had under the head of electric lighting by hydraulic power put the motor efficiency at 66 per cent., which seemed to be quite high enough. That would be working at full load. Sixty-six per cent. seemed to be the maximum obtained from the best water motors. The dynamo efficiency was quoted at 90 per cent. Further on in the paper the efficiency of dynamo and motor combined was put at 66 per cent. He thought the loss would be greater.

In connection with the question of gas energy as obtained from town gas, no reference had been made to the very interesting remarks of Mr. Denny Lane, in his presidential address at the Institute of Gas Engineers. He would commend that paper to Mr. de Segundo's attention, if he had not already seen it. He was quite willing to take the figures which Mr. de Segundo gave in connection with the installation of electricity at Bradford, but the total cost per kilowatt-hour was put at 2*d.*, and that seemed to be a very low figure with town gas at 3*s.* 3*d.* The author asked whether it was not possible to reconcile the interests of the gas companies and the electric light companies. He (Mr. Mead) believed that it was possible, and it was a thing which he had endeavoured to do, and he had tried to bring a Town Council to that way of thinking. It seemed to him that, if the cost of electric current generated by means of gas engines using town gas could be brought down to 3*d.* per kilowatt, proprietors of hotels and other large users of artificial light could put down a gas engine and generate electricity at about half the price they would pay to electric light companies for the ordinary current. That that view of the case had some foundation would be evident, he thought, by the fact that during the last fortnight he had been approached by an electrician, who said to him, "You are supplying gas in a certain town, and an electric light company is supplying light there. They are charging 7*d.* per unit. I can show large users of electric light how to put down a gas engine and generate their own current at about half the price." That was a startling statement, and he did not think that gas engineers generally were alive to the fact that they had such a possible future power in their hands The figures which Mr. de Segundo had brought before the Society confirmed the view that, sooner or later, the gas companies would be almost forced into the position of supplying electric light indirectly through their gas mains. There were many gas companies that would be very glad to do business in that direction where gas was made at a prime cost of 1*s.* 6*d.* per thousand, or less.

Mr. W. H. PATCHELL said he thought a couple of wha were now old tests of gas engines might prove interesting, as showing what might be done with gas used as an illuminating agent through the gas engine and dynamo. Those tests were as follows :—

Duration of Test.	Size of Engine.	Gas consumed.	Electricity generated.	No. of 16 c.p. Lamp-hours.	
				Electricity at 64 watts.	Gas at 6 cubic feet.
hours	nom. b.p.	cub. ft.	watt-hours		
6¾	9	2365	50,201	790	394
7	12	2870	52,862	826	478

With reference to the loss in the mains, he thought the author had placed it rather high at 12 per cent. If he came down to 5 per cent. it would be probably nearer the mark. There was a somewhat early attempt to convert the London Hydraulic Power Supply Company's service into electricity. He (Mr. Patchell) had a gas engine on the basement and a solicitor on the first floor; but the two did not pull together very well, so he tried to get the Hydraulic Power Company to run a motor driving a dynamo. The efficiency came out at about 40 per cent., which, at the price the Hydraulic Company charged at that time, was simply prohibitive. He had to get a current, paying 8*d.* for it, and saved money.

Mr. JAMES N. SHOOLBRED said that the paper contained some valuable information, but much of it required careful consideration before it could be discussed. While comparing the cost of gas as against that of steam and other motive powers, care should be taken to be precise as to whether coal gas or Dowson economic gas was meant, since with the latter about four times the volume was required as against the former to produce the same amount of power. Again, in the North of England the cost per ton of anthracite coal—used there preferably to coke in the production of Dowson gas—was from three to four times that of steam engine coal.

Another point, and a very material one in comparing the relative cost of gas, of steam, of water, and of electricity, and one to which hardly sufficient prominence was given in the paper, was that of the relative amount of capital required with the several kinds of motive power. That was quite distinct from the relative efficiency of the several machines used in the respective cases; and sometimes, and under certain local conditions, the question of capital dominated, if it did not even counteract that of efficiency—to a certain extent, at least. In the North of England, where steam power was readily applied, it was pretty generally admitted that the sale price of coal gas, to compete successfully with steam, even in small installations, must not exceed 2*s.* per thousand cubic feet; nor that of Dowson gas be more than 6*d.* per thousand feet.

Throughout the paper, the economy to be effected by using condensing engines as against non-condensing was, in the opinion of the speaker, and in the case of the majority of electric central stations, considerably overrated. The very careful series of experiments carried out by the late Mr. P. W. Willans, and chiefly set forth in his posthumous paper "On Steam Engine Trials," which was read at the Institution of Civil Engineers about twelve months ago, clearly showed that the condensation losses were much more considerable than was generally supposed; and also that, unless a large supply at a very low rate was available—Mr. Willans usually put this at not over $\frac{1}{4}$*d.* per thousand gallons—it would be more economical to dispense with condensation altogether.

Respecting the selection of different sizes of generating units, referred to in the paper, so as to ensure, even with the very considerable and rapid changes which were inherent to a supply of electrical energy, that the several units should be working pretty continuously at somewhere near to full load, it might be well to mention that, without going as far as Berlin for an example, there were several central stations in this country, using a selection of Willans engines, which afforded very good results in that direction; and that a very large measure of the acknowledged economy in the working of those stations was stated to be due to the care with which the selection of the various sized generating units had been made.

The writer of the paper must surely have been misinformed, when setting down the loss in an electric system of distribution at 18 per cent. Possibly, with high pressure, and with transformers in use, it might amount to even more than that; but with low pressure, and with properly designed mains, the average loss ought not to exceed, even if it reached, half the amount stated in the paper.

Attention was also drawn in the paper to the fact that coal gas could be used more efficiently (that was, a smaller amount of it would be required to produce the same amount of illuminating value) if the gas be exploded in a gas engine, whereby an electric machine was driven, supplying current to the electric lamps, than if the gas was supplied direct to gas burners which afforded the same illuminating value as the electric lamps. That result need cause no surprise, when it was remembered how much larger was the proportion of heating parts (those utilised for the explosion in the gas engine) in the composition of coal gas, than that of the illuminating ones, even where the gas had been specially prepared for illuminating purposes. Many years had elapsed since Bunsen, in his experiments on Manchester gas, showed that out of every hundred volumes, on an average eighty were heat-giving, while only eight were fit for illuminating purposes.

Mr. W. WORBY-BEAUMONT said he thought Mr. Dowson had overlooked the author's remark that ultimately all the questions raised resolved themselves into £ *s.* *d.* in the matter of cost and £ *s.* *d.* in the matter of result, but that they could not express every value in £ *s.* *d.*, for the same thing would have different values in different places and at different times. The author had shown in what way he would use the efficiency which he selected, and the way in which the value of a thing might be determined at any moment and in any place by putting the market value upon the material which was to provide the working fluid or the working heat. For instance, there was one point with regard to the efficiency of a gas engine. It was always expressed thermally with regard to the number of heat units which a cubic foot of gas was supposed to give, and the number of heat units represented by the work done by the gas engine for that cubic foot. As Mr. de Segundo had pointed out, if they estimated the gas engine with regard to the cost in thermal units of the coal required to make the gas, in the same way as they estimated the efficiency of a steam engine, with regard to the cost of the coal necessary to make the steam, the efficiency of the gas engine came out a very different thing from that with which it was usually credited. That was a new and useful way of looking at the subject, and it was one which scored very considerably in favour of the system so well known in connection with Mr. Dowson's name. For instance, if they took the steam engine as using the working fluid which was provided by the expenditure of a certain amount of fuel, namely, steam, but considered it without reference to its origin, as they did the gas in a gas engine, it could be easily proved that a good steam engine had an efficiency of 90 per cent. or more. That was to say, the engine would do 90 per cent. of all the work possible from the quantity of steam necessary to fill its cylinder up to the point of cut-off, and expanded down to the mechanically best release pressure. But that was not the way in which they looked at the matter. They looked at it from the point of view of the cost in thermal units of the material used to produce the steam. From that point of view Mr. de Segundo's figures were of very considerable interest, when they considered the proposition that more should be done by gas companies in electric lighting. The 12·6*d.* given by the author as the price at which the water could be obtained, could only be intended to refer to the cost price at which the Hydraulic Power Company could supply the water to its own motors. One point to which Mr. de Segundo referred was a matter of importance with regard to a probable or, as he thought, improbable invention. He observed in his paper, when considering the electrical question, "What is wanted to complete the analogy is the analogue of the non-return valve, and this, so far, has not been discovered." Then he went on to say that he did not think it very likely that it would be. He (Mr. Beaumont) would hardly like to go as far as that. With regard to the gas question, he was recently at the gas-works of the Corporation of Burton-on-Trent, where the matter of electric lighting had been taken in hand. The engineer of the works was the engineer of the town, and he had taken a very great interest in electric lighting, with the result that an installation had just been completed, adjoining the gas-works. They were not using gas engines to drive the dynamos, but they were using fine coke siftings, which might be considered as gas-works refuse, and that, with a little coal slack, gave the engine power at a very low cost. It might be that, after a time, the Corporation would adopt some such system as that mentioned by Mr. de Segundo, for it might be more economical to employ gas engines in distant places, where the gas was already laid on, than to lay costly electric mains. He had been informed that they were doing something of the same kind at Moreton Bay, and at one or two other places. Mr. Shoolbred had mentioned a point in connection with condensing engines. They had been using jet condensers at Deptford for rather more than twelve months; and although jet condensers would not give all the advantages that might be got, still a very great gain had been made by the use of them. The President had raised the question of forced and induced draught in boilers, and he referred particularly to his own preference for induced draught. Perhaps he might be able to inform the meeting whether, to his knowledge, the system was in successful use in this country. It was very much used in the United States, and there were many batteries and boilers all connected up together, with one system of flues evacuated by one or two fans. The system had been under trial in several ships, and it had been tried by the Admiralty. There was no doubt that the system provided the means of surmounting the difficulties connected with forced draught, the burring of tube ends and cracking of tube plates. Credit should be given to Mr. W. A. Martin for his work in that direction.

The chief points in the paper were those that the author made concerning the possibility of distributing power in the form of water and gas, and obtaining at the end of any length of distributing mains electric light at a cost less than even the cost at which it could be supplied at the present time by a good many companies. The paper contained valuable hints to persons interested in that subject.

Mr. H. O'CONNOR said he thought that the question was more one with regard to the price at which a good article could be supplied by different systems than that of thermal units. The question of distribution, which had not been very largely touched upon, would come in there. In the distribution of gas there was a very small percentage of loss, whereas in the distribution of electricity in the mains the loss was something like 20 to 35 per cent. if transformers were used; and in the case of hydraulic power there was from 10 to 20 per cent. of loss. As to the cost of the mains for the same distance and the same power, possibly the cost would be five times as much for electricity as for gas. As regarded the cost of hydraulic mains, of course they would have to be very much thicker than gas mains in order to stand the great pressure which would be put upon them. He observed in the paper that the loss in the cells was only put down at 10 per cent. Was not that rather a small figure? He would have liked to see some more detailed figures with regard to the question of the comparison of the light given from the different lamps with the same quantity of power. The quantity of gas was given in the paper as yielding a certain amount of light with the Wenham lamp, and giving 227 per cent. more light through using it in the form of an electric arc light. He should like to have a few more particulars as to that. Perhaps Mr. Sugg could give them some figures about it.

Mr. S. SELLON said it might be useful if the author would state the comparative cost of a hydraulic power plant and an electric plant. He (the speaker) wished to know whether hydraulic plant in London or elsewhere had been working long enough to give any relative figures as to the cost of the upkeep of the mains. The question of the possibility of gas companies taking up the matter and supplying electric light, had been pretty well threshed out that evening. He thought that Parliament had shown its wisdom in not allowing gas companies to have a continual monopoly.

Mr. SUGG said that in response to a suggestion from Mr. O'Connor, he would state that some years ago Dr. Siemens and he came to the conclusion, after a careful examination of the facts, that they might obtain the same amount of light if they took gas and turned it into electrical force from an incandescent light, as from the standard Argand burner; but if they used a highly regenerative burner, the gas would give very much more light. But then came the question of the usefulness or applicability of gas under every circumstance. Gas could be put into any court or alley and used for a gas engine. It would not be so easy to lay an electric main. As to Mr. de Segundo's suggestion that the gas companies should supply the electric light, he agreed with it, and he had for a long time advocated it, but none of the gas companies saw that it could be done. As to the laying down of electric mains, it would be found that there were a great many quarters in a town where it would not pay to lay one down for the few people who would be likely to use the electric light.

Mr. ARTHUR RIGG said that about ten years ago he put up a hydraulic engine in the City to drive a dynamo for 120 16-candle power lights. The machinery worked with absolute steadiness, and in no way would it be possible to drive an electric light installation better. The introduction of hydraulic power, so far as driving dynamos was concerned, came to an end because the then projected electric light companies were liberal in their promises to supply electric light at such low prices, as to do away with any possible competition from hydraulic power. He was glad to hear from the author that there seemed now to be some prospect of using hydraulic engines for driving dynamos, as hitherto they never had a chance, having been handicapped by the cost of pressure water. He believed that the lowest price now charged by the Hydraulic Power Company was 2*s.* per thousand gallons in the day-time, and 1*s.* 6*d.* at night; and even that reduction seemed scarcely enough to permit of hydraulic engines competing with the electric light companies. As to the economy of hydraulic engines, he quite believed that they could get an efficiency of 80 per cent. or more, but it was always wiser to allow for a little loss through wear or leakage, and take an efficiency of 75 per cent. from hydraulic engines as their general average. That gave the cost of 1 horse-power with water at 2*s.* per 1000 gallons at about 4*d.* per hour, and if, as Mr. de Segundo proposed, the night rate of 1*s.* per 1000 gallons were ever to be adopted, then each 16-candle power lamp would cost 2*d.* (for power alone) for every ten hours' running.

The ordinary reciprocating hydraulic engine must run very slowly, or there would be continual shocks as the piston and column of water behind it were reversed. There was also considerable friction owing to the small area of the ports, a necessity of their construction to mimimise the shocks by preventing too high a speed being attained. The revolving type of hydraulic engine ran at a higher speed than was usually considered possible, and the whole construction turned round, cylinders and all, with the fly-wheel. An ordinary ball governor was provided, by which the stroke became moderated so that the amount of water used corresponded exactly with the load, and it was extremely interesting to see how the stroke altered to the required length as the number of electric lights were reduced or increased, and the power required for driving them varied.

He had to give up electric lighting by means of that engine, because ten years ago it was perfectly hopeless to convince any one that it could be done at anything like so cheap a rate by hydraulic power as by a direct supply. In working a capstan by that engine, the stroke varied according to the load through the action of the governor, and the economy derived under the conditions of working a capstan represented more than half of the water consumed in driving such capstans as were now in general use. In that engine there were no shocks, because the water had a relative velocity instead of an absolute one, so that it was really always on the move, and had not to be stopped and set in motion again twice in every revolution. As compared with the Pelton wheel or any other form of turbine, hydraulic engines possessed the advantage of being positive in their action, and the ability to run at very variable speeds without loss of efficiency; whereas it was well known that turbines could only allow of very slight variations in speed without serious loss, and their average efficiency at variable speeds was by no means equal to their maximum.

Mr. A. P. **Head** said that the efficiencies referred to by the author as the ratio of what one got to what one paid for, was the most useful of all, regarding, as it did, the question from the point of view of the consumer. On that idea he had drawn up a comparison between eight typical forms of artificial light, taking as his standard the number of hours for which a light of 16-candle power could be maintained for one penny. He had excluded the arc light as not yet suitable for domestic use. The results which were shown in the following table were to him somewhat surprising.

The assumed prices were those which would approximately obtain in London, viz., gas, 2*s.* 6*d.* per 1000 cubic feet; electricity (central station supply), 6*d.* per Board of Trade unit; petroleum for Priestman engine, 3⅝*d.* per gallon; petroleum for lamps, 6*d.* per gallon.

In the case of the glow lamp driven by town gas engine, petroleum engine and Dowson gas engine, he had taken Mr. de Segundo's figure of 1*d.* per Board of Trade unit for establishment charges, in addition to the cost of fuel. The details of the petroleum and Dowson gas engines were derived from figures published by Prof. Unwin and Mr. Dowson, and those of the incandescent gas light by Prof. Renk. The result of the duplex oil lamp was taken from experiments made by himself, and were only approximate.

Method of Lighting.	Candle-power.	Fuel per Hour.	No. of hours of 16 candle-power for 1*d*.
Gas—			
Fishtail or slit	16	8 c. ft. of gas	4·17
Argand	16	5 "	6·7
Incandescent gas	55·93	5·29 "	22·2
Electricity—			
Glow lamp driven by town gas engine.	16	3·2 "	6·4
Ditto driven by Priestman petroleum engine.	16	·106 lb. petroleum	8·0
Ditto driven by Dowson gas engine	16	·141 lb. coke	10·6
Ditto driven by Central Station supply.	16	$\frac{1}{16}$ B.T.U.	2·67
Oil—			
Duplex oil lamp	17	3·2 liquid oz. petroleum.	8·85

It would be seen by glancing down the fourth column of the table that the incandescent gas light stood first for economy. The glow lamp driven by the Dowson gas engine, though second, was more than twice as costly, while that worked from the central supply was the most expensive of all, costing eight times as much as the first named. The oil lamp stood well up in the list, while the Argand burner and glow lamp driven by town gas engine were practically equal. The reason of the high efficiency of the incandescent light was probably the same as that mentioned by Mr. de Segundo to account for the superior economy of the electric light derived from gas engine power, over the light obtained from the same gas in an ordinary fishtail burner. The great heating power of the gas was utilised to render an infusible mantle white hot, instead of burning the gas direct.

It seemed somewhat suggestive that the domestic electric light, as now practically available, was eight times as costly as the most recent development of gas lighting. Therefore, he would suggest that it would be well to pause before rushing into electric lighting schemes, on the assumption that that form of light was, all things considered, the best, but rather try to adapt the existing facilities to the best use. Every town had its gas-works, its mains, and its house pipes, and if, by a small alteration in the fittings, a brilliant and steady light could be obtained at one-eighth the cost of the electric light, it seemed to him that the days of gas as an illuminant were far from being numbered.

Mr. Nelson Boyd said it appeared to him that the figure of 16,000 heat units for anthracite was rather high. He had always understood that the heat value of anthracite was 13,000, not 16,000 units. Perhaps the author would explain why he had taken so high a figure.

The President said, in reply to Mr. Beaumont's questions about the system of induced draught to which he had referred, that it was a well-known one, viz. the Ellis-Eaves system. It was in use in several steamers, but he was not aware that it had been used for land purposes except in the patentee's works, and there it had been in operation some years, and the plant had recently been considerably increased. He was strongly of opinion that it was a very advantageous system. The reason he preferred induced draught was, that it did not cause the burning or blow-pipe action on the tube plates or the ends of the tubes, assuming the boiler was a tubular one, nor did it give such localised heat as forced draught. When the latter was used in the navy and the mercantile marine, considerable trouble was frequently caused in the fire-box or combustion chamber and tubes, and which was no doubt due to the impinging action of the flame on the plates. With induced draught, which was after all only natural draught intensified, the flame was drawn into the tubes and away from the edges, and the boilers worked without damage even when the large amount of 114 lb. of coal per square foot of grate was consumed per hour, as exemplified in locomotives, even in continental ones, where frequently brick arches were not used, and that fact would emphasise the advantages and safety of induced draught. The draught was produced by small exhaust fans, one applied to each boiler. Each drew away the waste gases from the boiler through the interchanger, which was nothing more nor less than a large surface condenser. As the hot gases passed through the condenser to the chimney, the fresh air that was induced into the furnace was first drawn into the interchanger in an opposite direction to that in which the waste gases were travelling. In passing from the exterior atmosphere to the furnace, it passed along outside the interchanger tubes, and in doing so abstracted heat from the waste gases inside the tubes, leaving them to escape at a very low temperature, necessitating small capacity of ventilating fans, which was advantageous. The fans could be regulated in a moment to a nicety, from an almost quiescent state, under which the coal was simply kept glowing, to the full amount, even up to 100 lb. of coal per square foot of grate per hour.

Mr. de Segundo, in replying upon the discussion, said he was very much obliged to the Members for the way in which they had received the paper and manifested their interest in its details. His attention had been drawn to some slips on his part; but one or two criticisms were, he thought, due to misunderstandings. The President had stated that 26 per cent. efficiency had been reached in gas engines. He was aware of that fact, but he could only say that he had assumed that efficiency which one reasonably might be expected to be realised in a really good gas engine in ordinary practice. He thought that 26 per cent. was a little too high, and could not be relied upon. He quite agreed with the President's remarks as regarded his definition of the commercial load factor for certain purposes, and also as regarded induced draught. He was himself an advocate of induced draught, as a result of his own experience. He had been much interested in the President's statement as to the number of pounds of fuel consumed per square foot of grate in certain boiler trials, that being a most important factor in judging of the efficiency of a boiler. Some questions had been asked as to the nature of Van Rysselbergh's scheme of hydro-electric supply. The scheme consisted in putting up at a central station the most efficient type of steam engine which was now known, namely, the triple-expansion condensing engine, to generate water pressure, and at the various points in the town to be lighted by electricity he established sub-stations, consisting of water motors driving dynamos. Each sub-station had its network of mains, and those were connected by trunk mains, so that one could relieve the others in case of necessity, or during the period of light load. The President had referred to the remark in the paper that in hydraulic power stations more efficient engines could be used, and he had asked whether they were used. He (the author) thought that it followed of necessity that in a hydraulic power station a more efficient engine could be used than in an electric light station, because the triple compound condensing engine could be used, whereas in electric supply stations it had been shown that high-speed engines, coupled direct to dynamos, were best suited to the purposes of generating electric pressure under existing conditions, taking them all round. With a very efficient condensing engine they might gain considerably in efficiency, but they might lose as much as 10 per cent. in transmission, by whatever means were employed for transmitting the power to the dynamo pulley. As to the fact that they were being worked more efficiently, as heat machines, he thought it followed, from what had been said in the paper, that this must be so, inasmuch as a pumping engine worked at full power as long as there was water to be pumped. In an electric light station they might sometimes be running their engine at 90 per cent. of its speed when they had only 15 per cent. used, because the pressure had to be kept up. Unfortunately the electric pressure remained very largely a function of the speed of the dynamo armature.

It had been suggested that the author was ill advised in reducing efficiencies to a heat basis. Mr. Beaumont had kindly taken up the cudgels on his behalf in that respect, so that he need not go farther into that matter. Mr. Dowson stated that Professor Kennedy had recently alluded to a possible heat efficiency of over 80 per cent. The efficiency which he (the speaker) assumed in the paper was an average one. He had not taken the figures on his own responsibility. If he was not very much mistaken, he took them from Mr. Donkin's own work, a most valuable one, which he had recently published on gas and air engines. If they calculated the heat efficiency from the very highest temperature which was reached in the cylinder of a gas engine, no doubt the efficiency would be 80 per cent. or possibly more. But he had taken 2700° Fahrenheit as the average maximum temperature which was reached in a gas engine. That was, so to speak, the available useful maximum temperature. Of course the temperature might rise up to 3000 during the explosion of the charge, and come down again almost at once. It was interesting to know that gas at 3s. per thousand was cheaper for working an engine than steam up to about 14 horse-power.

He was much obliged to Mr. Nelson Boyd for drawing his attention to the error in the calorific value of anthracite. He did not think that Mr. Donkin had quite understood him. He referred to a statement in the paper, and objected that an engine consumed water and did not consume fuel. He (the author) had not intended to convey that it did. What he meant to imply was that if any heat was not necessary for the working of a steam engine, then obviously one ought to be allowed to subtract it. But if the amount of heat which was rejected by steam engines was subtracted from the total heat of combustion, there would be nothing left to work with. Believing that he was right in that contention, he could not help feeling that whatever heat passed through a steam engine passed through for some useful purpose, and that without it the engine would not work. It was upon that basis of thought that he had made the statement that the heat was utilised. Perhaps "utilised" was an unhappy word. His statement as to 35 per cent. did not refer to Mr. Dowson's plant. It was a very rough approximation indeed, for, as Mr. Donkin rightly remarked, no experiments as to the efficiency of a gas retort existed. At least he (Mr. de Segundo) could not find any, and he had to calculate the efficiency roughly for himself.

As to the by-products, he was perfectly aware of their existence, and he quite anticipated that those who were interested in gas would take him to task for not taking them into account. But as far as the working of a gas engine was concerned, the by-products were of no use at all. If they could be used to lubricate the engine or to cool the cylinder, or to assist in some other way, in the conversion of heat into work, he should consider himself justified in taking them into account, but for producing motive power they were absolutely valueless, although they helped to pay a dividend for the gas company.

The price which he had quoted for hydraulic power had been taken exception to by some of the speakers. That, again, was a point as to which he should not like to be too sure, but it seemed probable that if a sufficient demand for power existed during the night, or in the early morning, it would so reduce the cost of the production that it might in the future pay the Hydraulic Power Company to sell power for a shilling per thousand gallons.

He had not read Mr. Denny Lane's paper to which reference had been made, but he should endeavour to obtain it. Mr. Shoolbred had been good enough to call attention to the ambiguity of some of the statements as to the cost of generator gas, and for that he thanked him. The 12·6*d.* given in the paper was not the price of the hydraulic power to the consumer, but the total cost to the Hydraulic Power Company, including everything, such as rates, taxes, maintenance and depreciation. He should like to see the non-return valve which had been referred to by Mr. Beaumont. As to the loss in accumulator cells, he had put it down at 10 per cent. The way to effect economy in charging cells was to charge them at a slow rate and thus avoid a serious watt loss. He was pleased to hear Mr. Sellon's statement as to the comparative cost of hydraulic plant and electric plant. He had been very much interested in Mr. Sugg's remarks, and also in Mr. Rigg's engine. He had known that engine for a long time, and a very good little engine it was, because it possessed a power of governing which hydraulic engines generally did not possess. It was, of course, essential that hydraulic engines should be able to govern.

VACATION VISITS.

The usual Vacation visits, three in number, were made during the summer and autumn of 1894. The first, on June 5, was to the South Metropolitan Gas-works, Old Kent Road, London. The second, on July 10, was to the Royal Small Arms Factory, Enfield Lock. The third, on October 9, was to Messrs. Siemens Brothers and Company's Works, Charlton.

The following are general descriptions of the several works:—

THE SOUTH METROPOLITAN GAS-WORKS.

The South Metropolitan Gas Company was founded in 1834 and incorporated in 1842, the establishment in the Old Kent Road being the company's original works. In 1880 the Surrey Consumers' Gas Company was amalgamated with the South Metropolitan Gas Company, and in the same year the united companies absorbed the Phœnix Gas Light and Coke Company. Following this, in the year 1885, the Woolwich, Plumstead and Charlton Consumers' Gas Company and the Woolwich Equitable Gas Company were also absorbed. The Old Kent Road Works are in two separate portions—the old and the new. No extensions have been carried out here since the amalgamation with the Phœnix Company, as since that time new works have been completed at East Greenwich, which have been built and designed for the purpose of meeting the increasing demand for gas in the company's district. The other works of the company (five in number) are each situated on the river, and as a consequence coals are delivered into those works at cheaper rates than at Old Kent Road, where all the coal has to pass along the Surrey Canal. The position of the Old Kent Road Works is favourable for the distribution of gas and also for the sale of coke. The maximum manufacturing capacity is 9,000,000 cubic feet per day, equal to 900 tons of coal, producing 400 tons of coke for sale, 9000 gallons of tar and 27,000 gallons of ammoniacal liquor. These figures represent about one-fourth of the total maximum daily production of the company. All the coke produced at Old Kent Road is sold locally, the bulk of the tar is bought by tar distillers, and the ammoniacal liquor is made into sulphate of ammonia. Sulphur is recovered from the sulphuretted hydrogen produced in the manufacture of sulphate of ammonia. The company has recently reduced the price of gas to 2*s.* 4*d.* per thousand cubic feet, which is the lowest at which gas is supplied either in or near London. Gas is now being supplied to the artisan class by means of a prepayment meter, and meters of this type are now being fixed at the rate of 300 per week. Consumers of this description are supplied with fittings and a cooking stove, the hire for which is included in the price they pay for the gas.

The Royal Small Arms Factory.

The Royal Small Arms Factory at Enfield is a very extensive establishment, and the following gives an outline of the various departments, and of the work carried out in each. In the smithery the members inspected the processes of barrel rolling, sword and sword-bayonet rolling, stamping bodies, guards, bolts, &c., and forging various components. In the machine gun department is carried on the manufacture and repair of the Maxim, Nordenfelt, Gardner and Gatling machine guns. The barrel room is appropriated to barrel drilling, boring, turning, setting, rifling, and chambering. In the tool room is carried on die sinking, and the manufacture of mills, drills, tools and gauges generally. The sword department is devoted to the machining and mounting of swords, sword-bayonets and scabbards. Next comes what is known as the large room, which is noticeable for its size, having an area of 50,000 square feet and containing 1503 machines, requiring 10 miles of belting In this room the majority of the components in the rifle ar machined, such as bolts, guards, sights, &c. In the woodwor stocking department the rough and finished turning of the stock butts and fore-ends is carried on, also the fore-end groovin and figure machining. There is a special department wher screws are turned out by automatic machinery. In the grindin and polishing shop, swords, sword-bayonets, lance heads and shoes, and the components of rifles generally are ground and polished. In the hardening and tempering department, swords, sword-bayonets, springs and the general components are hardened and tempered. There is a browning department where barrels, bodies, &c., are browned, previously to which they undergo the operation of sand blasting. In the assembling department, the actions and rifles are finally assembled and put together. The various buildings contain an aggregate floor space of about 300,000 square feet, the plant being capable of producing 2000 magazine rifles, with their accessories (bayonet, scabbard, &c.), also 1000 spare barrels and bayonets, in addition to cavalry swords, cutlasses, boarding pikes, lances, &c., in a working week of 48 hours. The factory is worked by means of a total engine power of 1050 horse-power. The number of different operations in the manufacture of the components of the Lee-Metford rifle II. proper, is about 1500, and with accessories, such as sight protector, handguard, bayonet and scabbard, oil bottle and pull-through, the number is increased to about 1750.

Messrs. Siemens' Works.

The works of Messrs. Siemens Brothers and Company at Charlton are devoted to the manufacture of electrical plant and machinery and submarine telegraph cables. All the machinery in the shops is driven by electric motors. The new dynamo shop was first inspected. The work carried on here consists in the construction and erection of dynamos and alternators. The plant comprises two overhead travellers: one is mechanical and lifts 10 tons, the power is transmitted by square shaft and gearing; the other is electrical, and lifts 5 tons; there is one motor for each motion. The motors are 7 horse-power, 6 horse-power, and 5 horse-power respectively. There is a large facing lathe for central plates of alternators, and various lathes for turning and for boring out gap for armature in magnets. There are drills, working up to a hole 4 inches in diameter, and planing machines, the largest working over a surface 16 feet by 6½ feet. In the old dynamo shop general erecting work is carried on, the shop being fitted with the necessary machines. The milling shop contains milling machines for small parts of machines which are required in large numbers, capstan-headed lathes for screws and nuts, and grinding machines. In the gallery the shaping and insulating parts of dynamo armatures and commutators is carried on. In the bobbin shop armatures and electro-magnet bobbins are wound. In the fitters' shop, where general fitting work is done, are lathes, drills, &c., several of which are driven by separate motors directly geared to them. The manufacture of carbons is carried on in the carbon shop, where the raw material is ground under edge-rollers, mixed, warmed, moulded into a round block, and, then placed in the hydraulic press, whence it issues as a carbon rod. These are cut to length and then baked in ovens, first at a red heat, then at a white heat, after which they are slowly cooled down. Each furnace holds about 4000 feet of 10 mm. carbons.

In the rubber shop the raw rubber passes first through the washing rolls, under a stream of water, to rid it of mechanical admixtures such as sand, bark, stick, &c. It is then dried for some time, after which it goes to the mixing rolls, where various minera substances are incorporated with it, according to the nature o the use which is to be made of it. The mixing rolls are hollow and steam or water can be allowed to circulate through them The prepared rubber is then passed through the calendering rolls, after which it is ready for the covering machines. Three layers are generally put on the stranded conductor—firstly the brown pure rubber, then the white separator, and finally the pink jacket; the wire is then taped and taken to the vulcanisers which are heated by steam. After vulcanising, the wire may b finished off in different ways, as braiding, covering with ozokeri and sheeting. One of the most interesting departments is th central power and lighting station. The plant comprises thre tubular boilers of gun-boat type (two more were in course o erection at the time of the visit), each 18 feet long by 9 fee diameter, 400 indicated horse-power each, 140 lb. steam pressure. Steam is largely used for heating purposes, as wel as for the engines. There are four engines: one Belliss compound vertical enclosed, 300 indicated horse-power, running a 350 revolutions per minute, cylinders 15-inch and 23-inch by 10-inch stroke; three Willans compound transfer condensing

300 indicated horse-power each, running at 350 revolutions per minute, cylinders 14-inch and 20-inch by 9-inch stroke. There are four dynamos coupled direct to these engines: Siemens' H.B. $^{24}/_{36}$ type for 120 volts, 2000 ampères. There is a switchboard with regulating switches and measuring instruments. The distribution of the electrical energy is by means of underground lead-cased cables. Over the boilers are the condensers, consisting of 27 double-concentric cylinders; the steam passes through the annular space, while cooling water runs down inside and out. This water is used over and over again. There are in all fifty-four electric motors in the works:—thirteen of 48 horse-power each (four of those in the rubber shop are directly connected by spur gear to the rolls); seven of 20 horse-power each; two of 15 horse-power each (these are directly coupled to a worm shaft driving the calendering rolls in the rubber shop, and are constructed to run at two different speeds); eight of 10 horse-power each (one of these is directly coupled to a cable machine, another works the lift in the rubber shop); twenty-four of various powers, from 10 horse-power to ½ horse-power, mostly directly coupled to lathes and other machine tools. All the regulating and starting switches and measuring instruments required for large central stations are put together in the switchboard erecting room on massive slate slabs.

At the time of the visit the deep-sea section of the third Atlantic cable for the Commercial Cable Company was in the course of manufacture in the cable shop. The served core passes into the rear of the machine through the hollow shaft, which carries, in an iron frame, the bobbins for the sheathing wires. On rotating the frame carrying the bobbins, the cable being at the same time drawn along, the wires are laid spirally round the core. The bobbin carriers are actuated by cranks, worked by an eccentric, so as to maintain always the same relative horizontal position, thus obviating any twists in the wires. After the sheathing wires, the cable receives finishing layers of jute yarn and compound. With "Jumbo," the largest cable machine, 64 sheathing wires can be put on in one operation. The rate of working is about five nautical miles of deep-sea cable per machine per 24 hours. From the cable machines, the cable is led directly into cylindrical iron tanks, where it is coiled away and kept under water. There are 10 tanks each for 150 to 200 knots of cable, and 8 tanks each for 400 knots of cable.

The lead cable shop is used for the manufacture of lead-cased iron-sheathed cables for the underground distribution of large currents for electric light and power. The large stranding machine can lay up 37 wires at one operation. This strand is then covered with jute, dried, soaked in insulating material, and passed up through a hydraulic press. In this latter is a large ingot of cold lead which, under a pressure of 400 atmospheres is forced to flow out of the nozzle in a continuous pipe surrounding the wire. The final operation consists of serving it with jute and sheathing it with steel bands. These cables are intended to be buried directly in a trench dug in the ground. The show room constitutes a museum of all kinds of electrical and telegraphic instruments and apparatus, both historical and novel.

October 1st, 1894.

GEORGE A. GOODWIN, PRESIDENT, IN THE CHAIR.

THE UTILISATION OF TOWN REFUSE FOR GENERATING STEAM.

By TOM WILLIAM BAKER, B.A.

THE practice of the larger southern towns in England is that all fluid waste from dwellings is called sewage, and its disposal is provided for in these towns by different systems of treatment. There are, however, even now, some towns in the North where the pail system is still in use. The class of refuse treated under the latter system is not included in this paper, but what will be considered consists of the usual ashbin contents, street-sweepings and sludge.

The disposal of the ashbin refuse and street-sweepings in large towns has been a source of considerable trouble and expense to the local authorities, and several vestries in London are now paying 3*s.* per ton for its disposal, exclusive of the expense of collecting it. Consequently, if 70 per cent. can be utilised and barging saved, considerable economy must ensue. There appears at the present time no doubt whatever, that ordinary ashbin and street refuse should be dealt with by fire at the earliest moment and at the nearest possible point, as it soon becomes a prolific source of zymotic diseases. Consequently, prompt and localised destruction is particularly desirable, as railway conveyance or barging causes delay and contamination to the surrounding atmosphere.

In order the better to understand what ashbin contents consists of, the author appends the analysis of Mr. Joseph Russell, given in a paper read before the Sanitary Institute on February 10th, 1892, and which may be of interest, the same having been practically corroborated by several other authorities.

From the report of the London County Council on dust destructors, the average from several districts gives 260 tons per annum for one thousand of the population, although the actual quantities vary widely. Taking this into consideration,

Component Parts.	Average per 1000 Loads.				Percentages of Weight.
	tons	cwt.	qrs.	lb.	
Breeze, cinder and ashes	611	3	0	4	63·69
Fine dust	187	1	0	8	19·51
Vegetable, animal, and various mineral matters	44	3	3	20	4·61
Waste paper	41	1	1	20	4·28
Straw and fibrous material	30	18	1	6	3·22
Bottles 5000		..			0·96
Coal and coke	8	0	2	14	0·84
Tins	7	11	2	22	0·79
Crockery	5	5	0	0	0·55
Bones	4	12	1	1	0·48
Broken glass	4	11	2	2	0·47
Rags	3	15	3	16	0·39
Iron	2	0	0	20	0·21
					100·00

and the fact of the preponderant amount of combustible material which it will be noticed is present in this refuse, it is apparent that it should be disposed of by fire, not merely with a view to its destruction for hygienic reasons, nor yet to reduce its bulk (which is done by the destructors in present use, leaving only from 25 per cent. to 30 per cent. of ash and clinkers), but that the heat set free in the process of destruction should be utilised.

Professor Forbes and others have estimated the value of ashbin refuse at a much higher figure than results from practice, the various estimates ranging from 3 to 5 lb. of water evaporated per pound of refuse. Hitherto, in practice, this result has not been obtained, and according to statistics collected by Mr. C. Jones, M.I.C.E., from the larger towns using destructors with steam generators by the waste heat, 6 horse-power per cell burning from 6 to 8 tons every 24 hours, appears to be the average result. This result, doubtless, can be increased by the use of forced draught, at the same time enabling the furnaces to do a far greater amount of work as destructors.

These statistics no doubt include the disposal of the street sweepings, which must be taken carefully into account, they being the vehicle for moisture impregnated with effluvia, which during destruction absorbs some of the active heat from the more combustible ashbin refuse. As the various local authorities, particularly around London, are now anxious to use their powers under the Electric Lighting Provisional Orders, granted to them for laying down plant for lighting their districts by electricity, this appears to be the better and most direct method of using this source of gratuitous heat. At the same time there are water-works and sewage pumping stations requiring steam, as well as baths and wash-houses, which frequently belong to the local authorities, where the heat could be advantageously utilised.

There can be no doubt that the calorific value of the refuse is low, particularly when street sludge is used, and from results obtained by the author only 1 lb. of water evaporated per pound of unsifted refuse is actually obtained. With screened refuse, however, that is, with the paper and loose rubbish, commonly called breeze, taken out, a fair average of 2½ lb. of water evaporated per pound of breeze is the result. For some months past the author has been using this fuel in an ordinary double-flued Galloway boiler, 22 feet long, 7 feet diameter, with 22 cross tubes and steam jet forced draught, the boiler being used for boiling purposes. These results could only be obtained by burning the breeze in direct contact with the boiler, and could not be so obtained if used in a destructor and then passed through brick flues to the boilers; Mr. Jones's statistics, before referred to, are based upon the working of plant of the latter description.

The trouble in stoking, owing to the amount of ashes and clinkers, prohibits the general use of town refuse in boiler furnaces to any great extent. A very large boiler capacity and grate area, proportionate to the quantity of steam required, are necessary, far beyond that usually required for ordinary coal burning, and further, unless the refuse is mixed with coal, 60 lb. appears to be the maximum boiler pressure obtainable. Even with a strong forced draught in the ashpit, 80 lb. only has been obtained. Consequently, to make the use of the town refuse economical, in connection with the best modern steam engine practice, a greater heat must be available and a higher pressure attained. Moreover, in thickly populated districts all escaping vapours must be rendered innocuous, so that there are three conditions for consideration, namely:—

1. Facilities for stoking and cleaning the fires.
2. Burning up the obnoxious fumes.
3. Temperature of combustion to be raised to produce higher pressures.

First as regards facilities for stoking and cleaning the fires. The principle of the ordinary dust destructor in its general design is doubtless the best, viz. having the feeding hopper at the upper end, and the fire-bars at a lower level, continuing towards the cleaning doors, and having mechanically moved fire-bars bringing the refuse forward, allowing the green fuel to be gradually brought towards the fire, thus evaporating and burning up the moisture in it. Of the several designs of different makers, that known as Healey's appears to be a good type, and most advantageous when used with a forced air draught, although there are several other designs which are equally applicable, viz. Fryer's, Horsfall's, Wiley's, and Warner's.

In Healey's furnace the hearth plate is at an upper level, on which the refuse is fed and which, in its descent, travels on to a movable gridiron and from thence to the fire-bars proper. In order to keep the furnace at its full work, this continual feed is necessary; but Healey's movement of the furnace bars has the triple effect of feeding the furnace, clearing the clinkers off the bars and pushing them into a receptacle for removal. This is accomplished by resting the front of the fire-bars on the dead plate, the back bearer being a rotating cam-shaft with eccentrics, on which is fitted each alternate bar, which has a slot fitting these eccentric cams on their under sides. The other alternate bars are fixed to a bearer and in a recess on the front dead plate. On their upper edge another bar is fitted with a parallel ball and socket joint. The upper ends of these bars oscillate in a recess in the upper hearth plate. The fronts of the fire-bars also oscillate on the front dead plate, so that on the bearer shaft being rotated towards the front, the movable bars lift the clinkers and fuel forward off the fixed bars and a constantly clean fire is kept. At the same time new fuel is fed from the upper hearth plate. The shaft is rotated by a ratchet wheel worked by an eccentric from a rotating shaft at the furnace front, driven by the forced draught blast engine. The air blast is brought from a conduit under the ashpits by pipes on either side and opposite each other in the fore part of the ashpits. Special facilities are provided for clearing away the dust from the flues at all possible points, and a dust settling flue or chamber is also provided between the furnaces and the chimney, which is preferably on the back of the furnaces.

Hitherto the practice as regards the generation of steam has been to place a tubular steam boiler between the destructors and the chimney, leaving the walls of the flues to absorb a large quantity of the heat before reaching the boiler. Between the destructor and the boiler a Jones's fume cremator is frequently used, which consists of coke furnaces so constructed and arranged that the flues from the destructors conduct the gases over these fires by deflecting masonry, thus cremating them and rendering them innocuous by destroying the excess of moisture and effluvia which would otherwise escape as noxious vapour and condense in the atmosphere; and cause what has been recently described as an unmitigated nuisance.

At Cambridge, Messrs. Wood and Brodie's system of furnace is being adopted. It consists of a water tube, Babcock type steam generator placed in series between every two refuse furnaces. The waste gases are conducted through brick flues into a chamber under a V-shaped ash tray or pit, and then over its upper edges through the fire grate to the water tubes and ordinary setting of the generators.

At Warrington, a special refuse furnace has been erected in front of the furnace of a Babcock steam generator, the place of which it takes. It is fitted with forced draught, the refuse fuel being conducted by hoppers from the floor above to the furnace. The following are the results of working, which Messrs. Babcock & Wilcox have kindly supplied.

THE CORPORATION OF WARRINGTON.

Test of Patent Destructor Furnace with Unscreened Refuse.

Warrington Installation.

Date, noon to noon	Nov. 23rd and 24th, 1893.
Duration of trial	24 hours.
Nature of fuel	Unscreened refuse.
Total quantity of fuel burned	53,536 lb.
Quantity of fuel per hour	2,231 lb.
Total quantity of water evaporated	61,344 lb.
Quantity of water per hour	2,556 lb.
Weight of clinker produced	14,980 lb.
Percentage of clinker	27·9
Pressure of steam maintained	68 lb.
Temperature of air in boiler house	45° F.
Temperature of feed water	104° F.
Temperature of gases leaving damper	650° F.
Quantity of water evaporated per lb. of house refuse	1·14 lb.
Average temperature of copper wire test	2000° F.
Average air pressure (water) maintained	2½ inches.
Draught velocity in feet per minute	820 feet.

From the author's experience the system which recommends itself is that of placing a steam generator directly over the destructor furnace, so that the heat shall pass around or impinge directly on the heating surface of the generator. The ordinary generator furnaces are placed above the refuse furnace, and are used as supplementary furnaces to increase the temperature necessary for the higher pressure demanded, and also to cremate any obnoxious gases from the refuse furnace below. Where destructors are in use, and it is desired to utilise the heat from them to generate steam at high pressures, the generators may be arranged in a series adjoining the main flue to the chimney, and by connections the gases may be directed into their combustion chambers, and so utilised and cremated. Where it is practicable, however, to place the generators over the existing lower furnaces or destructors, it is greatly to be preferred, as being more effective.

There is no doubt that the gases from refuse are impregnated with a large percentage of moisture, and are of low temperature. This is shown by an analysis of the gases, where a preponderating amount of nitrogen is found, amounting to 22 per cent., and any contact with the side walls of brick flues has the effect of impairing the efficiency, the walls being always ready to absorb some of the moist heat, the surfaces necessarily having to be large. With these considerations it will be seen that to obtain the best effect the radiated heat must be absorbed directly by, and transmitted to the generator. This is accomplished by placing a reverberatory perforated fire-brick arch over the refuse furnace, with the generator above it, so that when an excess of green fuel comes down from the hearth plate, the regenerative heat from the arch assists to cremate the fumes before passing to the upper furnace.

There is no doubt that hand sorting of ashbin refuse will be largely discontinued on account of its degrading nature, and also from the decreasing price of bones, rags, waste paper, &c., making it less profitable than formerly. There will, therefore, be a proportionately greater quantity of animal matter to be disposed of, and the consequent effluvia must be constantly dealt with, so that an effectual fume cremator is absolutely necessary. These fumes it is proposed to cremate and destroy, with the assistance of the reverberatory arch, by the higher temperature of the combustion chambers of the ordinary and supplemental furnaces of the generators, this being their hottest part, the temperature of which will be never less than 1500° Fahr. It has been found that to effectually destroy refuse fumes, 1250° Fahr. is absolutely necessary, and it would appear almost impossible for any effluvia to escape after passing through these two heats. Means must also be provided for the admission of fresh oxygen into the combustion chambers if necessary, to complete combustion; the gases or fumes from the destructors might also be burnt through the furnace bars of the supplementary furnaces, if desired, when oil or producer gas is used as fuel.

The author has recently had some experience of the effect of escaping effluvia when saturated with moisture. It was proved in a recent law case that persons in close proximity to the 60-foot chimney shaft from whence it was alleged the foul gases were escaping, scarcely complained, but numerous complaints arose from those from 300 to 1000 yards distant, showing that it took that distance to bring the saturated effluvia to earth.

In some existing plants in which no utilisation is attempted, the cost of fuel for the crematory fires has been so great that they have been discontinued, but serious complaints from the neighbourhoods are now arising, thus showing the advantages of cremation.

The calorific value of refuse being low, it is necessary to provide ordinary generator furnaces to assist in raising the steam to the required pressure, for economical use as well as for cremating, as in several of the existing plants with the boilers in the flues, 40 lb. pressure per sq. inch is all that can be obtained, and at Warrington, as previously stated, 68 lb. only is obtained even with forced draught. In the ordinary furnaces of the generator good fuel should be used, and if a supply of Russian oil can be obtained, that or producer gas appears to be especially applicable.

Having now described the general principles of the generation and absorption of the heat by the generator, and having specially in view the use of the steam generated by it for electric light stations, viz. to assimilate the supply to the demand, the author will deal with the question from the latter point of view. It is well known that the demand for electricity during the day is so light, even where a fairly high load factor is obtained, that the use of the steam generating plant at even half its capacity would be an excess, so that a system of heat storage is necessary for the economical use of the refuse, as the destructors must always be at work. Any ordinary form of steam generator may be adopted, but the cylindrical dry-back marine boiler with two flues, or the inclined water-tube boiler of the Babcock and Wilcox type, are best suited. They are illustrated at Figs. 1, 2 and 3, and they are so well known as to need no further description. Fig. 2 is a section showing the method of connecting the refuse furnaces to either steam generator. Lancashire boilers, on account of their length, are not well suited to the present purpose, as the temperature of the gases in the combustion chambers frequently falls below 1250° F., and allows the moisture to pass away undecomposed.

In all cases the refuse gases are conducted into the combustion chambers or their hottest part, while in the marine form they are led to the space above the flues and opposite the tubes, the gases from the ordinary and crematory furnaces of higher temperature mixing with them. In the water-tube generators they enter the ordinary furnace from behind the furnace back, in both cases meeting with the partly incandescent fire-brick masonry, which assists in evaporating any moisture and destroying the effluvia. It is also necessary to keep the generators short, otherwise the feeding floors must be placed over the boilers with descending hoppers. This design also takes up more ground area for the inclined roadway, the other forms being conspicuous for the small space occupied by them.

Referring to the refuse destructor and steam generator combined, for dealing with 420 tons of refuse per week (which is an average quantity from several London vestries), some 6 or 8 sets would be required for electric lighting purposes. These would be in one battery, adjoining each other, the flues between the arches over the refuse furnaces and under the generators, would communicate with each other, so that any number of refuse furnaces might be coupled to one generator and its crematory furnace. For the day load, however, they should be worked in sets of three, so that the middle generator alone would have its ordinary furnace in use, the refuse furnaces below all communicating with the one generator by dampers being opened between them, and other dampers closing the two outer generators from the chimney flue. It will thus be seen that the two outer generators would be kept at the same working pressure as the middle one, and would always be available by their own furnaces being brought into use, so that the stand-by losses would be wholly taken up by the refuse. There would also be an excess of steam during the extreme light loads, which should be stored in the following manner:—

A tank or reservoir properly clothed to prevent radiation is to be placed as a roof to the boiler house, and in this tank near the bottom is to be fitted a coil of pipes. The waste steam would be taken into this coil, which is immersed in water, thus condensing the steam, and ejecting the condensed water into the tank itself, eventually filling it with practically distilled hot water every day, and this would be the case either with condensing or non-condensing engines. When condensing engines are used it will be preferable to filter the condensed water from the air pumps, and use this as feed water through the boilers, and thence into the storage tanks, as before described; but where non-condensing engines are used it would be better to allow the waste steam in the coil to heat up and boil the water in the storage tanks, in which would be deposited most of the impurities, the coil being connected by a system of steam flow and water return to the generators. Under these circumstances, a live steam feed-water heater and separator would be necessary to feed the generators during the light load, bringing into use the boiled storage water during the heavy demand for steam. When multitubular generators are used, care must be taken that increased internal tube area is afforded for the passing of the gases from the three refuse and crematory furnaces. This system can be applied to existing destructors, as water-tube generators may be made of a width to suit such circumstances, where probably cylindrical boilers could not be so placed.

The net result of this system would probably be that ¾ lb. of water would be evaporated per pound of refuse, allowing for the lesser value of street sweepings or sludge, and the absorption of a certain quantity of heat in the furnace masonry, as compared with the 1 lb. of water per pound of refuse which has actually been accomplished, as before explained—a result which is corroborated by Mr. A. Collins, A.M.I.C.E., of Reading, and the Warrington tests in directly-fired generators. Reducing this to financial terms, the saving in barging, which has been mentioned as the only credit, must be first considered. This, according to the average cost to several of the London vestries, amounts to 3*s.* per ton after collection, and 70 per cent. can be utilised, leaving only 30 per cent. of ash and clinker as a residue to be disposed of, which, in the spring, is readily marketable for road making. Where crushing machinery is in use it can be prepared for mortar, and, with cement, manufactured into street paving. This source of profit will, however, be absorbed by the cartage on the unsold residue, also by the fuel account for the generator furnaces, for working the forced draught and moving the furnace bars, the net saving being therefore the cost of barging or disposal of 70 per cent. at 3*s.* per ton; and, taking 6 furnaces burning 10 tons each every 24 hours, equal to the consumption of 420 tons per week of 7 days—294 tons at 3*s.* will represent the saving in barging amounting to 44*l.* per week, or 2288*l.* per annum.

The gross credit will be the value of the steam generated from the refuse. As each furnace will be of a capacity to burn 10 tons every 24 hours, and taking 20 lb. of steam per indicated horse-power per hour and non-condensing engines without the cremating fires, the effective evaporation will be equal to 35 indicated horse-power per hour per generator set and available for electric lighting.

From the returns of the various London electric lighting plants published in *Lightning*, 1*d.* per unit appears to be a fair average for the cost of coal. Six destructors and generators would give an hourly output of 210 indicated horse-power from refuse only, or, allowing 15 per cent. for frictional loss = 177 electrical horse-power, which, at 1·34 horse-power per unit = 128 units at 1*d.*, or 11*s.* 1*d.* per hour, say 93*l.* 1*s.* 6*d.* per week, against which the extra cost of maintenance, wear and tear have to be debited. If ashbin refuse alone were burnt, the results would be 15 to 20 per cent. in excess of this, and this result could only be attained if the steam were used by the engine as generated; but against this, and as a general debit, the inherent losses of storing the heat and the re-heating will have to be considered. As this process will be going on for two-thirds of each 24 hours, the author estimates this loss at 30 per cent., but being 16 hours only out of the 24 = 20 per cent. on the total 35 indicated horse-power, leaving a net effective result (after deducting 15 per cent. for frictional losses) of 23·6 electrical horse-power per hour per set, which may be absolutely depended upon. The total value, at 1·34 horse-power per unit, equals 1*s.* 5½*d.* per hour per set, or 8*s.* 9*d.* per hour for the 6 sets; that is—

	£
73*l.* 10*s.* per week, or per annum	3822
Less 350*l.* for steam for auxiliary blast and grate engines and pumps	350
	£3472

Mr. G. Watson, C.E., of Leeds, in his paper read before the British Association in 1892, gives the theoretical value of ash-bin refuse as 1 lb. evaporating 2·13 lb. of water, and the practical result at 1*d.* per indicated horse-power per hour with a steam generating plant of improved type, or 1*s.* 3*d.* per cell per hour, burning 5 cwt. of refuse at a total cost of 1*s.* 10*d.* per ton. At Oldham, some authorities give the cost at 1*s.* 6*d.* per ton, including all expenses and depreciation. Taking these figures and the evaporative tests of the author, of Mr. Collins, and those from Warrington, the foregoing figures may be considered fairly substantiated, together with the results deducible therefrom. The ordinary or supplementary furnace heat is not considered in these estimates, as that would be directly available for extra evaporation at proportionately increased returns.

The author considers, as previously stated, that a plant capable of dealing with 420 tons of refuse per week would be of suitable working capacity for a London vestry. The plant would consist of eight refuse furnaces (two in reserve) with six steam generators for 140 lb. working pressure with feeding, coal and cleaning floors, forced draught, machinery, movable fire-bars, storage tanks and chimney, and capable of a total output of 900 brake or electrical horse-power when fully loaded. The author estimates the cost at 18,000*l.* including 3000*l.* for the site.

The maximum indicated horse-power from the refuse only is computed at 48 horse-power per cell, the extra evaporation by the supplementary furnaces at high load utilising the remainder of the heated feed water out of a total of 20,000 gallons.

The following is a statement of the returns, which are inclusive of engineers' charges and royalties.

	£		£
To wages, renewals, repairs, oil, lighting, depreciation, water, &c., at the Oldham estimates at 1*s.* 10*d.* per ton	2002	By value of heat ..	3472
Yearly payment for redemption in 25 years of interest at 3½ per cent. and principal on a loan of 18,000*l.*	1092		
Credit balance	378		
	£3472		£3472

	£
From heat account	378
„ saving in barging	2288
Net saving	£2666

The quality of ashbin refuse varies greatly. During the summer it is generally very poor, but from the better districts of London it may be advisable to sift it over a shoot during early spring, reserving the better fuel which it will be found to contain for use in the ordinary furnaces during the summer, and thus increasing the economy. From inquiries the author finds that the refuse from some localities would not repay this necessary outlay. The author's experience is that the Paddington siftings have been fully 25 per cent. less in value in July than in March, which has caused a lower evaporative average value to be given than the individual tests before referred to by others, as on individual weeks in January to March the breeze was particularly good, which is shown by the water and quantity tests.

The author has endeavoured to place the complex question of the disposal of town refuse in a practical light before the Society. The obtaining of the facts has been the outcome of the necessity of obtaining a cheap fuel for slow steaming, and of utilising refuse for producing electricity. The author's experience in connection with electric lighting since 1878, particularly when required for factories, is that would-be users first ask themselves—" Have I engine or boiler power to spare." The idea of a separate plant using a waste product has been, until the past few years, quite foreign to the question. It now, however, may be said to solve an important problem. It will probably be admitted from what has been stated, that in addition to meeting sanitary and hygienic requirements, this system of refuse utilisation constitutes a valuable source of profit, to which public authorities are at length becoming alive.

DISCUSSION.

The PRESIDENT said he thought it would hardly be necessary to ask the meeting to pass a hearty vote of thanks to Mr. Baker. The paper was a most valuable one, not only on account of what it contained, but also on account of the discussion which he felt sure it would evoke. The subject was a most important one, and was absorbing the attention of all sanitary engineers. The matter was one which must deeply interest everyone, and it was astonishing that the system of destroying town refuse had not been introduced at a much earlier date. He would ask Mr. Baker, before the discussion commenced, to elucidate the paragraph which began "A tank or reservoir properly clothed to prevent radiation, &c.," as it was somewhat difficult to understand the exact mechanical arrangement to which the author had alluded. He would ask the speakers who took part in the discussion to confine their remarks as much as possible to that which he understood to be the subject of Mr. Baker's paper, namely, the system of utilising town refuse, rather than a detailed description of the construction of the various destructors. He understood the author's system to be, shortly stated, the combination of destructor and boiler in such a form that the hot gases from the destructor impinged upon the boiler immediately above the destructor; and the author had shown a way of carrying that out. The paper appeared to bear rather upon the system of generating steam by the use of the destructors, than upon any description of the destructors themselves.

The vote of thanks was unanimously accorded.

Mr. BAKER said that in order to further elucidate the paragraph to which the President had referred, he might mention a practical example which he carried out at a brewery some two or three years since. It was necessary to boil water in a hop back containing about eighteen hundred gallons. At the time he was called in a coil at the bottom of the back or tank condensed the water from the boiler, and it was delivered into the yard as hot water, and wasted. He closed up the outlet and put a return tube back into the boiler. The result had been that he had been able to save two hours in the time of boiling the water, with an economy of something like 2 cwt. of coal. The 1800 gallons had been boiled in four hours with 6 cwt. of fairly good coal. That had been done with the same coil-pipes placed in the bottom of the tank, with an inlet from the top of the boiler, and with an outlet from the coil feeding into the water level of the boiler the steam being taken from the top of the boiler near the safety valve. His principle was that the combustion chamber, which was the hottest part of the boiler, was used to cremate the gases and destroy all the nitrogen in the refuse. The President had asked him as to the use of the coils in the storage tanks with condensing engines. That system was to pass the feed water through them from the air pumps, and to eject the water from the coil into the tank itself, after it had been filtered and condensed, thus filling the tank with both distilled and heated water, ready for the night load.

Mr. F. H. CHEESEWRIGHT said the only fault he had to find with the paper was that the author did not speak in such glowing terms of the use of the refuse as fuel as he thought he ought to do. It would, perhaps, have made the paper too long if it had embraced an account of all the principal steam raisers and cremators of dustbin refuse. There were, however, cremators which would raise steam simply by the refuse being cremated, and he thought they ought to have been noticed. The author said, "With screened refuse, however—that is with the paper and loose rubbish, commonly called 'breeze' taken out—a fair average of 2½ lb. of water evaporated per pound of breeze is the result." The cremator with which he (Mr. Cheesewright) was intimately acquainted, namely, that on the Livet system, gave 3·3 lb. of water evaporated for every pound of unsifted refuse consumed. In Westminster, within a short distance of the present meeting hall, there was a partial installation on that system, a Lancashire boiler being set with the Livet expanding flues. That installation had been at work for the last four months, and he could not do better than draw attention to the following statement of the surveyor of the parish, Mr. Wheeler (at whose instigation the installation was erected), on the subject respecting it. "The furnace provided all the steam which worked the machinery, as well as the electric light dynamo. There was one load of clinker left to every four loads of dust." The fuel which Mr. Wheeler had to deal with was dustbin refuse which had been gathered from the poorest districts of the parish. It contained no coal, and was very bad; this was proved by the clinker that was left behind, which was very soft and easily crumbled under a light pressure. "During the past three months there had not been many fires going, and the bulk of the refuse collected had been vegetable stuff." In the winter it was expected that better refuse would be obtained. The Government offices would provide them with that. Mr. Wheeler reported that "there was no smoke visible from the chimney, neither was there a smell in the depôt or in the vicinity of the furnace; and the amount of work which the boiler was able to do furnished sufficient proof that the Livet system was a good one, and that, with the multiplication of furnaces, either in one or in more depôts, you could not only burn all the dust and refuse of a district, but also supply power which must be of use to the community." Mr. Wheeler had invited the parochial surveyors of the metropolis to an inspection, and on the occasion of their visit there was a pressure of 68 lb. of steam. There was the equivalent of 180 16-candle-power lamps being developed, and there was all the machinery running in the workship, and all that power was produced entirely from using dustbin refuse alone as fuel. He wished to call particular attention to the fact there had been an installation running without consuming one pennyworth of coal, and supplying all the steam which Mr. Wheeler considered necessary for electric lighting and driving the machines in the workshop. That result had been obtained for fourteen weeks, with a saving to the parish of 160*l.*, and the electric lighting had cost nothing. He would ask Mr. Baker the height of the chimney which was used in the destructor of which he had given an account. In the Livet system the height of the chimney was an important fact. The chimney at Westminster was nearly 50 feet high, and there was no smoke or steam or anything perceptible issuing from it.

Mr. BAKER said that the height of the chimney referred t by Mr. Cheesewright was 30 feet.

Mr. CHEESEWRIGHT said that a test of the Livet system at Halifax was made in October last year. The time of starting was 12.35, and the time of concluding was 6.35, so that the test lasted six hours. The fuel used was the Halifax refuse. The tota amount burnt was 5694 lb., and the quantity per hour was 949 lb. The total quantity of water evaporated was 17,248 lb. the quantity evaporated per hour was 2874 lb. The weight o clinker and ashes produced was 1939 lb.; the weight of matte actually burnt was 3755 lb. Pressure of steam maintained 50 lb.; temperature of air in the boiler house, 52° F., agains 45° F. at Warrington. Temperature of the feed water, 49° F. against 104° at Warrington. Temperature of the gase leaving the damper, 300° F. Temperature of the gase between the fourth and fifth flues, 380° F. Smoke observed none. Quantity of water evaporated per pound of refus burnt, 4·5. Quantity of water evaporated per pound of refus actually fed into the furnaces, 3·2 lb. Draught velocity, 75 feet per minute. The combustion was so perfect that neithe smoke, dust nor odour emanated from the chimney stack. He observed it stated in the paper that the temperature in the furnace, as taken by the copper wire test, was 2000° F. He could not understand how it was that, with a temperature of such magnitude, so little water was evaporated. Better results than those stated would have been obtained at Westminster if the Livet system had been set up there in its entirety, as at Halifax, instead of only a partial installation. What he considered to be the great point of the Livet system was that no auxiliary machinery of any description was required. The draught was produced by the flues gradually expanding as the velocity of the gases decreased. That was the secret of the success of the system. The air entered the furnace bars with a velocity of between 700 and 800 feet per minute, and as that velocity was lost, so the area of the flues increased. The boiler was of the ordinary Lancashire type, and was surrounded by the heat which was generated by the gases given off by the burning material. As soon as the fire was lighted, the system commenced to work.

The PRESIDENT inquired how the temperature was got up and good combustion obtained without a forced draught.

Mr. CHEESEWRIGHT said that the combustion was caused by the great velocity of the air passing through the fuel which had to be burnt.

Mr. PERRY F. NURSEY said that the question of the utilisation of town refuse as fuel for steam raising was a very important one, and was largely engrossing the attention of borough engineers just now. Referring to the Livet system, the installation of which in Westminster had just been described by Mr. Cheesewright, it might be interesting if he (Mr. Nursey) briefly described an installation at Halifax (Yorkshire) which he tested early in the present year. The generator consisted of two Cornish boilers, each 23 feet 6 inches long by 5 feet 9 inches diameter, with a 3 feet 5 inch flue, the flue being set eccentrically. Each of the boilers had six Galloway tubes, and was connected with a superposed steam chamber, 24 feet 6 inches long by 6 feet 6 inches diameter, by five tubes or legs, each 4 feet long and 14 inches diameter. The water level was at about half the diameter of the steam chamber, the remaining half forming the steam space. The feed water was heated by being passed through three tubes placed in the central and side flues and running the entire length of the boiler, the tubes being connected at one end with the feed water tank and at the other with the steam chamber just below the water level. The setting was on the Livet principle, which consisted of a series of flues gradually increasing in area from the back of the boiler to the chimney flue, and having expansion chambers at the back and front of the boiler, the arrangement being such as to insure the utilisation of all the heat produced. The course taken by the products of combustion from the furnace was through the boiler flue, returning by an outside flue to the fire-door end, then by an inside flue to the back of the boiler, then by an inside upper flue (in which the legs were placed) to the front, and finally by an outside flue to the chimney stack. The total length of the flue was 115 feet, and the gases had to travel that distance in touch with the boiler before they entered the chimney. The chimney was 120 feet in height, 3 feet 6 inches internal diameter at the base, and 3 feet 11 inches at the mouth, thus carrying out the Livet system from first to last. The following are the particulars of the test which he made on February 23rd, 1894:—

Time at starting	11.30 a.m.
Barometer	29″·5
Atmospheric temperature	43° F.
Wind velocity (fresh, gusty, south-westerly)	658 ft. per min.
Normal temperature of feed water (taken from town supply and measured by Kennedy meter)	45° F.
Fuel used, town refuse screened from dust only.	
Velocity of air entering ash-pit (right-hand furnace	459 ft. per min.
Velocity of air entering over fire (right-hand furnace)	1952 ,,
Velocity of air entering ash-pit (left-hand furnace)	481 ,,
Velocity of air entering over fire (left-hand furnace)	1560 ,,
Temperature of feed water at time of feeding, and taken at point of entry to upper chamber	240° F.
Time at finish	4.30 p.m.
Barometer	28·7° F.
Thermometer	42° F.
Temperature of feed water supply	42° F.
Water evaporated	17,800 lb.
Fuel consumed (town refuse)	4,628 ,,
Water evaporated per lb. of refuse	3·84 ,,
,, from and at 212° F.	4·60 ,,
Fuel (refuse) burned per hour	926 ,,
Smoke pale and thin, and only seen occasionally at firing up.	
Obnoxious fumes to leeward of chimney and in boiler house	nil

Mr. Nursey added that after his test he examined one of the central boiler flues, and found about a ¼ inch deposit of fine dust on the top of the right-hand boiler, and a similar deposit on the nearest leg, and on the feed water heater. That, he was informed, was the result of some four months' intermittent orking, the expansion chambers acting as traps, in which the dust settled. He considered that his test demonstrated the efficiency of the Livet system of utilising town refuse for generating steam. He might mention that some three or four years ago he inspected the Livet system of boiler setting, as applied to an ordinary Cornish boiler at some works at Chelsea, where town refuse was being used as fuel. He was present for several hours, during which time steam was steadily maintained at 50 lb. pressure, being supplied to an engine and used for other purposes, no higher pressure being required. The results there were entirely satisfactory.

Mr. C. JONES said he should like to know from Mr. Nursey the cost of the Livet installation to which he had referred, as cost was an important factor in the calculations of engineers. Several systems had been introduced, and he hoped that several more would be forthcoming. England was quite large enough to afford scope for more systems than at present existed. It was of no use to bring schemes before engineers unless they had some data to go upon rather more to the purpose than the details which were sometimes supplied to them. He had not come to the meeting as the advocate of any system, though he had taken an interest in what might be called the low temperature system rather than the high temperature system. He had nothing to say against high temperature systems if it could be proved that they did their work in a thoroughly economical manner, but the question was one of economy. He relied very little upon the details which had been given to the meeting as to experiments carried out with certain forms of destructors. They had been told of one which lasted the whole of six hours, but he could put no faith in such a test. For his own part, he should prefer the test which would be afforded by the working of the system for six months, or twelve months. or even for ten years, such as had taken place at Ealing. That would give them something to fall back upon, because it was not a test carried out in the presence of the inventor. It must be remembered that the engineer was not always standing near the destructor, and that there were many hours in the night when, although the work was done, it was not done at high pressure. That was an important point for consideration. He was very glad to hear from Mr. Cheesewright a reference to Mr. Wheeler, because he knew that whatever Mr. Wheeler put before them might be depended upon. He (Mr. Jones) did not hesitate to say, after long experience, that during the summer months they might get ten tons of refuse in the course of the day, in which there would not be any ashes worth noticing. During last from the chimney, neither was there a smell in the depôt or in the vicinity of the furnace; and the amount of work which the boiler was able to do furnished sufficient proof that the Livet system was a good one, and that, with the multiplication of furnaces, either in one or in more depôts, you could not only burn all the dust and refuse of a district, but also supply power which must be of use to the community." Mr. Wheeler had invited the parochial surveyors of the metropolis to an inspection, and on the occasion of their visit there was a pressure of 68 lb. of steam. There was the equivalent of 180 16-candle-power lamps being developed, and there was all the machinery running in the workship, and all that power was produced entirely from using dustbin refuse alone as fuel. He wished to call particular attention to the fact there had been an installation running without consuming one pennyworth of coal, and supplying all the steam which Mr. Wheeler considered necessary for electric lighting and driving the machines in the workshop. That result had been obtained for fourteen weeks, with a saving to the parish of 160*l.*, and the electric lighting had cost nothing. He would ask Mr. Baker the height of the chimney which was used in the destructor of which he had given an account. In the Livet system the height of the chimney was an important fact. The chimney at Westminster was nearly 50 feet high, and there was no smoke or steam or anything perceptible issuing from it.

Mr. BAKER said that the height of the chimney referred to by Mr. Cheesewright was 30 feet.

Mr. CHEESEWRIGHT said that a test of the Livet system at Halifax was made in October last year. The time of starting was 12.35, and the time of concluding was 6.35, so that the test lasted six hours. The fuel used was the Halifax refuse. The total amount burnt was 5694 lb., and the quantity per hour was 949 lb. The total quantity of water evaporated was 17,248 lb. the quantity evaporated per hour was 2874 lb. The weight o clinker and ashes produced was 1939 lb.; the weight of matter actually burnt was 3755 lb. Pressure of steam maintained 50 lb.; temperature of air in the boiler house, 52° F., against 45° F. at Warrington. Temperature of the feed water, 49° F. against 104° at Warrington. Temperature of the gases leaving the damper, 300° F. Temperature of the gases between the fourth and fifth flues, 380° F. Smoke observed none. Quantity of water evaporated per pound of refuse burnt, 4·5. Quantity of water evaporated per pound of refuse actually fed into the furnaces, 3·2 lb. Draught velocity, 750 feet per minute. The combustion was so perfect that neither smoke, dust nor odour emanated from the chimney stack. He observed it stated in the paper that the temperature in the furnace, as taken by the copper wire test, was 2000° F. He could not understand how it was that, with a temperature of such magnitude, so little water was evaporated. Better results than those stated would have been obtained at Westminster if the Livet system had been set up there in its entirety, as at Halifax, instead of only a partial installation. What he considered to be the great point of the Livet system was that no auxiliary machinery of any description was required. The draught was produced by the flues gradually expanding as the velocity of the gases decreased. That was the secret of the success of the system. The air entered the furnace bars with a velocity of between 700 and 800 feet per minute, and as that velocity was lost, so the area of the flues increased. The boiler was of the ordinary Lancashire type, and was surrounded by the heat which was generated by the gases given off by the burning material. As soon as the fire was lighted, the system commenced to work.

The PRESIDENT inquired how the temperature was got up and good combustion obtained without a forced draught.

Mr. CHEESEWRIGHT said that the combustion was caused by the great velocity of the air passing through the fuel which had to be burnt.

Mr. PERRY F. NURSEY said that the question of the utilisation of town refuse as fuel for steam raising was a very important one, and was largely engrossing the attention of borough engineers just now. Referring to the Livet system, the installation of which in Westminster had just been described by Mr. Cheesewright, it might be interesting if he (Mr. Nursey) briefly described an installation at Halifax (Yorkshire) which he tested early in the present year. The generator consisted of two Cornish boilers, each 23 feet 6 inches long by 5 feet 9 inches diameter, with a 3 feet 5 inch flue, the flue being set eccentrically. Each of the boilers had six Galloway tubes, and was connected with a superposed steam chamber, 24 feet 6 inches long by 6 feet 6 inches diameter, by five tubes or legs, each 4 feet long and 14 inches diameter. The water level was at about half the diameter of the steam chamber, the remaining half forming the steam space. The feed water was heated by being passed through three tubes placed in the central and side flues and running the entire length of the boiler, the tubes being connected at one end with the feed water tank and at the other with the steam chamber just below the water level. The setting was on the Livet principle, which consisted of a series of flues

Mr. F. A. Robinson said he observed in the paper that some of the most important calculations were based upon the steam consumption of the engine being 20 lb. of steam per indicated horse-power per hour; and yet the author said that the boilers could not keep steam in them at more than 50 lb. pressure. The author also stated that the engine was non-condensing. He (Mr. Robinson) took it that the engine was a simple and not a compound one, as at such a pressure they could not work compound, and nothing was said as to condensers being used. He should like to ask the author what kind of engine he used which would work with 20 lb. of steam per indicated horse-power per hour, when the initial pressure of the steam was only 50 lb.

Mr. G. Watson said that at Leeds they were making very rapid progress in the matter of steam raising from refuse with the Horsfall destructor. Mr. Bennett, in a paper read before the Institution of Civil Engineers, gave 6 indicated horse-power per cell, and he (Mr. Watson) had worked it out, and he found it equivalent to $\frac{1}{4}$ lb. of steam raised, to about 60 lb. pressure per square inch per pound of ashbin refuse. Professor Forbes wrote a letter to the *Times*, which had been very severely commented upon, and in which he said that the ashbin refuse of a community was sufficient to light each inhabitant of each house with an 8 candle-power lamp two hours every night. That would approximate to one pound of steam per pound of unsorted ashbin refuse. They had now heard representatives of the Livet Company saying that they could get 4·5 lb. of water evaporated at Halifax from one pound of unsorted ashbin refuse.

Mr. Cheesewright: 3·3 lb., I think I said.

Mr. Watson, continuing, said that the statement made by Mr. Cheesewright was 3·3 lb. for Westminster and 4·5 lb. for Halifax. He would take it as 4·5 from the feed water. As ashbin refuse generally contained 30 per cent. of moisture, and as 30 per cent. of clinker remained after the refuse was burnt, there was evidently only 40 per cent. of combustible matter in the refuse to commence with. If the evaporation per pound was worked out, it would be found that it came to 11·2 lb. of water per pound of combustible matter in the refuse. That was better than the best Welsh steam coal. In spite of the names which had been brought forward in support of that statement, he must say that he could not subscribe to it. Mr. Baker had been much more moderate in his paper, and he thought that they ought to confine themselves a little more to Mr. Baker's paper, and a little less to new matter of a very contentious description. But Mr. Baker neglected to state to what pressure he raised his steam. That was, of course, a matter of the very greatest importance.

The President: The paper says 66 lb.

Mr. Watson said he was sorry he had overlooked that figure, but a lot of claims had been made from time to time without any statement of the pressure to which the steam was raised. He should like to call attention to the importance of stating the pressures reached. He thought it quite possible that a pound of steam might be raised to 60 lb. pressure from one pound of ashbin refuse, at certain times of the year at all events, but it had not yet been done. The best result that had been obtained to his knowledge was half a pound of steam raised to 70 lb. pressure per pound of refuse. That was done at Oldham. He measured the result himself, and it had been corroborated to some extent by others. The whole value of the utilisation of the steam power depended, of course, as had been pointed out, upon the number of hours during which it could be utilised. The sum stated by Mr. Baker as having been saved would amount to 2*s.* 5*d.* per ton of refuse burnt; which represented the value of the refuse for fuel. But he (Mr. Watson) did not think that that value could be obtained without working more hours a day than was practicable in connection with most electric lighting installations.

Mr. Baker had, however, brought forward a system of storing the heat. He (Mr. Watson) admitted that he did not fully understand it; but he failed to see in what respect it was better than Mr. Druitt Halpin's system, which was thoroughly scientific, and had been proved to a limited extent at all events. Mr. Baker had not given them a description of any system which would fully utilise the power, since the heating of feed-water would only require a small proportion of the waste heat. Mr. Crompton, in his paper at the Institution of Electrical Engineers, had given the cost of fuel as only 1*d.* per unit out of a total of 5*d.* or 6*d.*, and this showed how easy it was to exaggerate the saving that might be effected. It seemed to him that destructors might be most usefully employed for driving tramcars, because the tramcar stations were placed in different districts in the town, and the destructor stations might very well be put there in order to save cartage. He calculated that, if they could evaporate half a pound of steam to 70 lb. pressure from 1 lb. of unsifted refuse, the value of the power for driving tramcars for, say 17 hours per diem, would be nearly equivalent to 3*s.* a ton, and that, of course, would be thoroughly worth securing. He quite agreed with all that Mr. Jones had said about the tests. He did not himself believe in these tests of destructors at all. Even a 24 hours' test, or a 48 hours' test, was not sufficient. With regard to the Warrington test, nothing had been said as to labour, and they had been left in the dark upon a number of other important points, notably the grate area, which some people seemed to think a matter of no consequence. He did not dispute the results. He had heard recently of a 24 hours' test of a furnace on the Horsfall principle, designed by Mr. Hewson, and made 7 feet wide instead of the usual 5 feet, in which 20 tons of refuse were burnt in 24 hours, every possible means being taken to get that amount through the furnace, regardless of labour. There was no doubt that the amount burnt at the tests depended entirely on the skill and energy with which the men worked. Mr. Baker's apparatus was certainly a step in advance in many respects, but he thought that it was a mistake to put the boilers on the top of the furnace. He could not imagine that in a furnace so arranged the top of the boiler would be less than 18 feet from the ground level, and it would be necessary to build a platform from which to clean the boiler tubes. Further, he failed to see how the furnace could be repaired without the whole structure being taken down. He thought a much better arrangement was that designed by Messrs. Brodie and Wood, and now in course of construction at Cambridge, in which the boilers were placed between the furnaces. The scheme in that case was for sewage pumping, and it was proposed to use the ashbin refuse during the greater part of the time for raising the power. When the load required to be heavier they used coal in an auxiliary furnace to raise more steam. He believed that placing the boilers between the furnaces was the proper plan for adoption where steam raising was the main question. In conclusion, he wished to give a word of warning as to the absurd schemes which were constantly being brought forward in connection with this question. It had been frequently said of late that each person ought to burn his refuse in his own grate, as if our domestic smoke were not already pungent enough. In Chicago a destructor was said to be at work which went from door to door, and burnt the refuse as it travelled. He supposed that English engineers must not object to that method so long as it was confined to Chicago, but he hoped and believed that they had got beyond that arrangement in this country.

Mr. W. Spinks said he quite agreed with the view that the first duty of a local authority was to get rid of the material without committing a nuisance, and that the utilisation of the power obtained must be a secondary consideration. The tests at

Warrington were undertaken by two gentlemen in the employ of the Leeds Corporation, well known both to Mr. Watson and to himself, and they publicly confirmed the tests at a meeting at Liverpool on the 25th ultimo. Since the Leeds test, a test was made on the 27th August by the Borough Engineer of Burnley, extending over seven hours, and the amount of material burnt closely corresponded with that in the Leeds test, but the residue of clinker was 17 per cent. instead of 27, as stated in the papers. At the meeting of the British Institute of Public Health, the Chairman of the Committee which had charge of the works at Warrington, who is an iron manufacturer, stated that the only fuel which was purchased at Warrington was half a ton of coal a week to start the furnace on Monday morning. Warrington, unfortunately, was upon the pail system, and the medical officer of health had told him that they had 8000 pails collected weekly, and the whole of the material, including both urine and excreta, was evaporated in Fryer's Evaporators, and the whole of the power for working them was derived from the very furnace which Mr. Baker had referred to. In his (Mr. Spinks') opinion the arrangement of the furnace at Warrington most completely confirmed the correctness of the method which Mr. Baker had advocated. The boiler tubes impinged on the hottest part of the furnace. A good deal had been made of the calorific value of the refuse. One of the gentlemen who took the test at Warrington stated, at the meeting in Liverpool on the 25th ultimo, that the time of the test was during the coal strike, when anything that was black was regarded as coal. Mr. Jones stated three or four years back that at Ealing the refuse material was getting less and less valuable every day. One day he (Mr. Spinks) made an experiment to see what could be done in burning coal completely, and in his own dining-room, with a measurement of about 2800 cubic feet, the fireplace being 13 inches by 10 inches, having a Teale fireback, the thermometer outside being about two degrees above zero on the day selected, he burnt 35 lb. of coal, and got 1·14 oz. of fine ash.

There was another point which Mr. Baker and other speakers had lost sight of in dealing with the question. Upon the credit side there was not a word about the decreased cost of loading the material. He found that there were many places on the open ashpit system, where it cost something like half-a-crown a load to cart the material to a tip to dispose of it, apart from the cost of collecting. Where a destructor could be put in a central position, as it could without committing a nuisance, the carts could bring in about 10 loads a day, at a cost of something like 10*d.* a load, or even less than that, as against half-a-crown. That would go a very long way as a set-off against the interest and sinking fund on the capital outlay. He did not think that that saving could have been taken into account in Mr. Baker's estimate. Some of the speakers had referred to the Livet system. Those gentlemen representing the company had referred a great deal to their work in Yorkshire, and it was interesting to meet them again that evening, because he had thought that they had been lost altogether. He and others would be very glad to see them back in Yorkshire, and if they returned, he should advise them to get a little lower down into the South Yorkshire coalfield, for instance, at Barnsley or Normanton, or Castleford. They might get something there in the refuse which would give them 7 lb., instead of the 5 lb. which they had told the meeting about.

The discussion was then adjourned until the next meeting, 5th November.

November 5th, 1894.

GEORGE A. GOODWIN, President,
in the Chair.

THE UTILISATION OF TOWN REFUSE FOR GENERATING STEAM.

By Tom William Baker, B.A.

Adjourned Discussion.

The author placed before the meeting a supplementary diagram (Fig. 4) illustrating his system of conserving the heat energy in waste steam, together with the following description.

At the last meeting, when my paper was read, the President asked me to give some further particulars of my heat storage arrangements, which I now beg to supply. To further illustrate my proposed system, I show in the diagram, Fig. 4, the steam generator and heat storage tank with their connections. A is the steam main supply pipe connecting the generators with the engines; B is an automatic balanced steam valve which allows the escape of any steam in excess of that required for the engines into the condenser coil C, situate at the bottom of the storage tanks with an outlet at D, which is connected as the condensed water return to the generator by the valve E. The action of this apparatus is as follows:—The waste steam will be conducted through the coil which is immersed in the water in the tank (if used with a non-condensing plant) and the heat of the steam is transferred to this water; the condensed water in the coil returning through the valve E to the steam generator.

Where carbonate and sulphate of lime are present in the feed water with a non-condensing plant, these impurities will be precipitated in the storage tanks; the live steam feed water heater, heating up the water to 300° F., setting up the separation on its entering the tank and afterwards settling in it. Means are provided for preventing it depositing on the coil, so that practically pure, hot feed water will be available without pumping under pressure. In condensing plants the feed water having been filtered in coming from the air pump, it may be condensed and ejected into the storage tanks through the boilers having been previously purified. Or it may be delivered directly into the tanks, and there reheated as in non-condensing plants.

It should also be observed that any generators not actually in use for the day load will also be additional storage reservoirs. In cases of pumping stations, or where the demand for steam is fairly constant and heat storage is not necessary, it may be preferable to use a series of destructors, communicating with the combustion chambers of one or more generators on the same level. The special advantages of placing the generators over the destructors are the heat storage taking up the stand-by losses, and the reduced area required.

The President said that notwithstanding the author's further explanation he could not understand the diagram. If the water passing through the coil was condensed live steam from the boiler simply circulating round he understood the arrangement very readily; but from the description he had been under the impression that it was the waste or exhaust steam from the engine, and steam that escaped from the safety valve of the boilers, that was taken up into the storage tank, and that the heat which was there stored was thus truly waste heat. Mr. Baker now stated that the coils were under boiler pressure. If that was the case then he (the President) had evidently misunderstood him and he could not help thinking that other persons might have been equally misled.

Mr. Baker said that the waste steam went through the balanced valve and the valve would not open necessarily until there was a pressure of say 140 lb. or the set working pressure in the boiler, which he proposed to work at. No steam would go through the balanced valve until it exceeded the 140 lb., which would occur also when the steam was in excess of the demand for the engines. The valve would again open and throw its waste or condensed steam into the coils in the tank. The action went on remarkably well, although he doubted at first whether it would do so. The waste was at boiler pressure. It had nothing whatever to do with the exhaust steam from the engine. The word "exhaust" appeared in the paper, but it ought to have been "waste."

The President asked Mr. Baker to follow the process one step further and state how the heat was utilised after it had been stored in the storage tank, and how it was conserved from radiating. Did Mr. Baker represent that the heat given off in the condensation of the steam was used simply for feed purposes, or was there any other method of using the heat when it was in the storage tank?

Mr. BAKER said it was used entirely for feeding the boilers. It was passed through a live steam feed-water heater before it got into the tank. Steam at 140 lb. would be about 340° F., and that being a live steam feed-water heater it would set up such heat as to set free the carbonate and sulphate of lime and allow of its precipitation in the storage tanks. Means were provided to cover the coils so that the precipitation should not impair their efficiency by settling on them. The water would be purified from organic matter and become ready for the boilers. The tank would be a covered one and properly clothed to prevent radiation.

Mr. WM. SPINKS said that it would be seen from the diagrams that the boiler used by the Warrington Corporation was a Babcock and Wilcox. The position shown on the section was not that advocated by Mr. Baker. The boiler was not directly over the furnace. When he spoke at the last meeting he did not refer to the time in which the heat could be raised up to what he might call a valuable point. Mr. Button, the Borough Engineer of Burnley, made some tests on the 27th August last. At 10 o'clock the boiler was quite cold, and at 11.28 the first charge was put in and began to burn. At 11.50, something like 11 cwt. of unscreened town refuse had been consumed. Warrington was a town on the pail system, there were something like 8000 pails in use, and there was the ordinary refuse together with vegetable and animal matter. In 1½ hours, a temperature of 2000° could be attained. The boiler had been working at Warrington for the last 15 months for 5 days in the week, and had been burning 24 tons of unscreened town refuse per day of 24 hours, continuously from Monday morning to Friday night. No special preparation of the refuse was required, and the Corporation propose to put in another destructor of precisely the same type. He believed that some other Corporations had decided to adopt the same system, and others had the matter in contemplation. Some time ago, Mr. Jones called attention to the working of his destructor, and he called it white slavery. Mr. Darley, of Leeds, called it "hell-fire work," because the men had to work at 2000°. It was well known, however, that gas stokers worked at a temperature of from 2200° to 2400° in the ordinary stoking of retorts, and the men who worked the puddling furnaces at the forges had to stand a temperature something like 3400°, so that he failed to see where Mr. Darley's definition came in, especially as labour could be got at 24s. a week, and there seemed to be no lack of it. It was stated by Mr. Deas at the Sanitary Institute meeting in Liverpool, at which Mr. Jones was present, that the present cost at Warrington was 5½*d.* per ton and he hoped to reduce it to 5*d.* It was undoubtedly the fact that they were getting through from 20 to 24 tons a day without difficulty, and they were raising a high amount of power from the unscreened refuse.

A good deal was made at the last meeting of the amount of steam that was raised by the Livet system at Halifax. He believed that it was admitted by the promoters of that process that the tests were not made upon unscreened town refuse, but that a certain amount of Haigh Moor or other coal was used to get the 5·84 lb. which so astounded those present at the last meeting. He believed that the extreme tests were only of 5 hours. He lived within 16 miles of Halifax, and he had been invited to go over and see the tests made, but he had never been invited in such a way that he could go when a continued test was being made. The only test he was acquainted with was that of 5 hours made by Mr. Nursey, and described by him at the last meeting. Nothing was said as to the unscreened town refuse, which contained miscellaneous articles. He believed that all the basis of calculation in other destructors had been taken upon unscreened town refuse, pure and simple. If engineers were to make a comparison with the Livet system, he should like to know whether *their* tests were made with unscreened town refuse. If they were required to add gas tar, or paraffin oil, or coal, of course it was no use to discuss the matter. He was not an advocate of any one particular system, for he was a sanitary engineer more than a mechanical engineer, and, as he had before said, the first consideration for the local authority was to get rid of the material without creating a nuisance, and to do so at the least possible cost. The utilisation of the material for producing power was a secondary consideration.

Mr. Perry F. Nursey said that with regard to Mr. Spinks remarks on the quality of the fuel used in the Livet furnace perhaps he might be allowed to repeat what he said at the last meeting, with respect to the fuel used by him at the trial he made of the Livet system at Halifax, on February 23, 1894 The material was town refuse screened from sand, and it consisted of ashes, animal and vegetable refuse, broken pottery bones, rags, straw, paper, &c. It was simply screened from road sand. There was no coal whatever mixed with it, nor was there any paper (except the stray pieces in the refuse) or any other such substance used. The test was a plain straightforward test, and the result was 3·84 lb. of water evaporated per lb. of fuel, and not 5·84 lb., as was stated by Mr. Spinks. He (Mr. Nursey) had nothing whatever to do with any outside statements of results, made by certain parties connected with the invention, which were in some respects, he did not hesitate to say, grossly exaggerated. He stood by the results of the trial which he had himself made, the figures of which he had given in his professional report to the proprietors of the destructor, and which were largely quoted by him at the last meeting, and which figures were good enough for anything with the fuel used.

Mr. **Druitt Halpin** said he did not yet understand the system upon which the author was working with his storage. Was the tank a closed one or an open one, or under what pressure did it work?

Mr. **Baker** said that the tank was a closed one, but there was no pressure.

Mr. **Halpin** said that he was still greatly in the dark as to how the system worked. He thought it might possibly work microscopically, and if it worked, it could be greatly helped by a steam loop. He did not see how any reasonable quantity of work was to be got out of it under the circumstances if, as the author said, its action depended on the safety valve. Steam ose up the pipe and condensed, and steam condensed all along he coil, and it would be seen that steam condensed in the down pipe coming into the boiler on one side. In the down pipe at he return side there was a check valve. If they took the esistance of the check valve on one side, where the water entered as equal, and, in addition to the resistance of the urplus valve on the other side, he thought it would be found, even in the most favourable circumstances, that they were pretty nearly in a state of equilibrium all round, and, unless a team loop or something of the kind was put on it, he did not ee how it was to do any reasonable amount of work. With egard to the author's remarks about the deposition of dirt, any of the feed-water heaters did it. As the author's apparatus did not go beyond 212° F., which it physically could not, according o what the author had said, no matter what steam was in the pipe, it could not deposit all the dirt. It could only deposit he least injurious part of it—namely, mud—which would come down almost mechanically. It could also deposit the lower orms of carbonates, but it could not touch the other forms of arbonates or the sulphites at all, so that the most dangerous part of the dirt was all left in the water. He thought it was nown that under 312°, or something like that, they could not ring down the last of the sulphites.

Mr. E. E. **Glaskin** said that there appeared to be some mis-

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apprehension with regard to the circumstances under which certain tests were made of the Livet boiler in Halifax. The tests were conducted under his control, and there was never, to his knowledge, one particle of coal used. It would be most foolish for any engineer to jockey any test which he might make, because such tests were the only data by which engineers could gauge the practical working of one system in comparison with that of another. It was never anticipated that everyday practice would come up to the tests that were made under trial. In the Halifax tests all the usual conditions were most rigidly observed. Some of the tests lasted for six or seven hours, and they were always determined by the engineer who, with his own assistants, conducted the trials for the public body whom he represented, and the time could be extended to any number of hours at that engineer's discretion. Some of the tests which had been quoted were made with screened, but others were made with unscreened refuse. In the one case there was from 30 to 40 per cent. more power derived than in the other. The Halifax installation was at work for over six months of the year continuously. As Mr. Spinks lived so near Halifax, he could have come and made any examination he chose.

With regard to the storage tank which Mr. Baker had described, he (Mr. Glaskin) took the same view of it as Mr. Halpin. It seemed that steam was created and carried up into the storage tank and brought back to the boiler, thus completing the circle; and as the pressure from the boiler was the only means of sending the steam up into the tank to be condensed and forced back again into the boiler, there was evidently an absolute balance of power, except that the steam might rise through the up pipe after it had passed the balance valve, propelled by the head due to the difference of density between the water and the vapour or steam.

With regard to some of the remarks which had been made at the last meeting, it did not appear to him that there wa so much want of harmony in the result of the experiences which were described as at first sight appeared. He had found that in different towns there was the greatest difference in the refuse which was delivered, so that the results might be entirely different in different places. Even in various sorts of coal there was an immense difference in the thermal energy, and much more would there be in the variety of refuse. Then again there were great differences in the manner in which the combustible was treated in different places. Would any engineer think of firing with coal by dumping a ton at a time on to th fire bars and emptying the furnace every one or two hours and expect an economical result? Yet such was the method by which the refuse was burnt in the ordinary destructor. Again, there was a great distinction between coal and refuse as a combustible, coal being comparatively homogeneous and refuse heterogeneous. Refuse contained highly combustible substances of a bulky nature, which were consumed immediately upon being thrown on the fire bars, leaving large spaces which would allow the cold air to rush in and cool the products of combustion in the flues. In Mr. Nursey's test the refuse was burnt on the fire bars in precisely the same way as coal in an ordinary steam boiler. He (Mr. Glaskin) did not know any fairer or more exact way of determining the heat of a furnace than by the chemical analysis of the products of combustion in the chimney. Taking the analysis of four large centres of population where they were using the ordinary destructor he had found that the carbonic acid did not in any case exceed 2½ per cent. of the products of combustion in the chimney, whilst he products of combustion in the test which Mr. Nursey made contained 7·1 per cent. of carbonic acid according to the analysis made by Messrs. Bevan and Cross, and any engineer ould for himself calculate the difference between the number of hermal units in that case and those in which the carbonic acid was only 2·5 per cent.; whereby it would be found that there was nearly four times more thermal energy in the one case han the other. A question was asked at the last meeting as o the reason why short chimneys gave so much draught. The ordinary flue constructed upon the formula laid down by James Watt, contracted in area as the gases were reduced in volume due to the abstraction of heat in their passage to the chimney. The principle involved in the hypothesis was that he chemical affinity of the carbon, hydro-carbons and oxygen would proceed along the line of least resistance, being impelled by the difference of density due to difference of temperature, and that therefore as the volume of the resultant gases is greatest over the furnace, they must for the continuation of he process be released either by reduction of temperature or he provision of increased room for expansion; or both, as was done in this case, first, by the boiler abstracting a large portion of the heat, second by increasing the area of cross section of he flue in proportion as the volume of the gas is decreased, hereby producing a lateral as well as direct motion to the gases; in the same manner as would obtain when a gas issues hrough an orifice in the division between a high and low-pressure chamber, when it is found that the curve of least esistance is that of a parabolic cone, the base of which is (the point of balanced densities) farthest from the orifice. In this pplication of the hypothesis, the furnace is the chamber of highest, and the atmosphere the chamber of lowest pressure the flue is the orifice in the division between the tw chambers, and the chemical affinity of the elements promotin combustion is the force or head impelling by increase o volume the gases through the expanding flue and chimney, or as may be shortly stated, the draught is obtained by the energ of condensation.

He (Mr. Glaskin) wished to thank Mr. Baker for his valuabl paper, and to call his attention to the fact that he had omitte to include the friction on the dynamo, which would amount t 10 or 12 per cent. on the unit actually delivered; also to th fact that he had made an allowance of from 30 to 35 per cent for the reduced value of the steam generating power of coal du to the variation of the load, whereas Prof. Kennedy, who ha made some elaborate tests at the Westminster Electric Ligh and Power Station upon the loss of the efficiency of coal due t the variation of load, found the lost efficiency to be as muc as 45 per cent.

Mr. E. Manville said that at the end of 1892, the vestr of Shoreditch consulted him as to the adoption of the destructor system, and he in conjunction with a committee o that body inspected many destructors. The result was tha the vestry decided to put up a destructor in combination wit an electric lighting station, but hitherto that decision had no been carried into effect. Near the beginning of the paper, th author stated, on the authority of Mr. C. Jones, that onl 6 horse-power per cell, burning from 6 to 8 tons every 24 hours appeared to be realised at present. That was a point whic he (the speaker) believed had misled many local authorities Of course, at most destructor works there had been no necessit for utilising the steam that might be generated, except fo their own small work, and in no case, with one exception, wa there anything like the requisite amount of boiler heatin surface to utilise all the heat emanating from the burnin refuse. It generally happened that when a local body visite works they took into consideration nothing but that whic they saw in operation before them; and he knew cases i which they had given up all idea of utilising the heat o account of their not having seen use made of the steam t any great extent. It might have been well to remark upon that fact in the paper. The one exception, of which he had spoken, was the destructor at Warrington, where practically the full calorific value of the burning refuse was daily utilised.

In another part of the paper, the author observed that before they could hope to raise steam to a higher pressure than 60 or 80 lb., the highest known temperature of the destructor furnace must be raised. In those destructors where a forced draught was used, 2000° and more could be depended upon; and he had yet to learn that that was not a sufficiently high temperature to raise steam to 120 lb. pressure, representing a temperature of about 300° F. He agreed that the addition of coal might be at times a great advantage, not to raise the temperature of the destructor gases, but to assist them in generating a larger volume of steam than these gases could produce at times of heavy loads. In another part of the paper, the author referred to the various types of boilers which might be used, and after noticing the Babcock and Wilcox inclined water-tube boiler, he went on to say, "Lancashire boilers, on account of their length, are not well suited to the present purpose as the temperature of the gases in the combustion chambers frequently falls below 1250° F., and allows the moisture to pass away undecomposed."

Mr. Baker said that in a Lancashire boiler with a number of cross tubes, the combustion chamber, which was the place at which he inserted the gases for destruction, often did fall below 1250° F.

Mr. Manville said that he presumed then that Mr. Baker meant that in other types of boilers, the gases passed through and were sent off to the chimney at a temperature of 1250° or more. He should think, therefore, that there was room for economy in the further utilisation of the heat so lost, and that a system for the utilisation of hot destructor gases which involved their dissipation at that temperature was one rather to be avoided than adopted—in the economical consideration of the subject. Feed-water storage was one of the most important features to be considered, but hardly that method suggested by Mr. Baker. He (Mr. Manville) did not quite understand the arrangement, but he thought the system ought to be carried much further than shown in Mr. Baker's diagrams. In a refuse utiliser burning 420 tons of ash-bin refuse per week, and used in connection with an electric lighting station, a large portion of the power which might be used was being wasted during the daytime and other times of light load, and the power so wasted should be stored up to meet the demands of heavy load time.

Most engineers were aware of at least one well-worked out heat storage system, in which not merely the feed water was heated, but all the energy obtained was bottled up and made available for use, with only such loss as might occur from radiation and conduction. He referred to Mr. Druitt Halpin's system. He thought that such a system as that would be of much greater advantage in connection with an intermittent steam generator, such as a destructor boiler must be, than the method proposed by Mr. Baker.

The evaporative duty of various qualities of ash-bin refuse must always be in dispute. The first thing a local authority had to consider, was that the refuse should be burnt thoroughly and rendered innocuous, and after that was accomplished, the waste gases might be utilised in doing that, no doubt. A great deal of the heat was necessarily lost; and he thought that the statement that 1 lb. of ash-bin refuse would evaporate 1 lb. of water from 212° F., was a very fair statement. Hence the economical value of ash-bin refuse for steam raising could not be doubted, and that was the important point to be pressed upon those to whom it was open to adopt the system.

Colonel Fosbery said that for some time he had had charge of the installation on the Livet's system at Halifax, and he had taken every precaution to ensure that the evaporative duties of the furnaces should be correctly ascertained. He had found the general evaporative duty of refuse, out of which the mere dust had been extracted, to be from 3 lb. to 3·5 lb. as Mr. Nursey had stated. He was prepared to answer for those figures, having himself checked them for a period of three months. In his opinion the proper way to use town refuse was to place it directly under the boilers, and consume it there in direct contact with the evaporative surfaces. It was true that during a portion of the testing time the furnaces were stoked by hand, and allowance must be made for that as having a distinct advantage over mechanical feed. The tests began in May and extended to the end of August, a period when town refuse was at the lowest calorific value. Moreover, the people at Halifax burnt their cinders two or three times over, so that the residue from their grates was absolutely unconsumable rubbish. The material which was sifted out was chiefly that rubbish. No smells arose from the destructor, and there were no forced draughts. A fine natural draught was produced by the Livet system of gradually increasing the area of the flues from the furnace to the chimney.

Mr. Charles Jones, in reply to the President, said that he had no doubt that the figures the author had quoted from him were correct. They were taken from practical every-day working. It must, however, be remembered that, so far as Ealing was concerned, the destructor was never used without the "Fume Cremator." At the same time the sewage sludge, which was very moist, was all burnt with the house refuse. As he had said before, municipal engineers had simply to get rid of the refuse without creating a nuisance, and to do so at the smallest possible cost. If they dealt with the matter as put before them by the advocates of the Livet process, the question of screening must arise. It ought to be absolutely and definitely settled what they were to understand by the term "ordinary screening." Screening was screening, whether it was done by machines or by hand. Screening cost money, and it took away some of the most difficult material that they had to deal with. A very serious question which was raised in some towns had been put to him again and again. It was, Can you deal with the road drift in the destructor? That point had not been touched upon, but it had to be continually dealt with. It was of no use to ignore questions which were coming up, in order to back up some particular system. He had the most perfect faith in the statements which had been made as far as the experiments had gone; but that was not sufficient; they wanted to know what the result of a continuous working out of a given system would be? It was necessary to take to their boards something more definite than test experiments. What was the use of experiments which lasted only from May till August? Nothing less than 12 months' working could satisfy them.

Mr. Glaskin wished to correct a misapprehension on the part of Mr. Jones. The experiments referred to by Colonel Fosbery were afterwards continued under his (Mr. Glaskin's) supervision from the period at which Colonel Fosbery terminated his office until the following May; so that the year demanded by Mr. Jones as the period necessary for a proper test was complied with.

The President said that, with regard to the question of the calorific duty of ash-bin refuse, it appeared to him that all the various speakers were right, and yet all were wrong. The quality of the refuse must vary considerably in different towns, and it even varied considerably in different parts of the same district. The only way to settle the question was to make an analysis of the refuse, and compare the evaporation of water in pounds to get the number of pounds of carbon burnt in the refuse. The results arrived at must be theoretical, but they would be very useful for establishing standards and making comparisons.

Mr. C. Mason said that the main point for consideration in combining a steam generator with a refuse destructor was to so arrange the generator that it should be immediately in contact with the fire. To secure that, they covered over or threw on one side the refuse-charging orifice. That, in his opinion, was the main objection to Mr. Baker's proposal, as the generator had to be elevated away from the refuse cremator, thus necessitating dual stoking arrangements. He should like to know how the general arrangement of Mr. Baker's destructor would work out, as it appeared that too much space was required for its adoption in a confined situation. Something had been said about throwing down refuse by the ton. As a fact that was what was, and must be done, as the refuse was always brought in in loads of considerable capacity, and must not, for sanitary reasons, be stored, but must go direct into the cremator. He thought that was the fatal point in Livet's generator as a refuse destructor, as charging through the furnace doors was a tedious process, and the refuse would become a nuisance before it could be put into the furnace. It would be interesting to know the quantity of sand mentioned by Mr. Nursey as being screened from the refuse of Halifax, as he had never known such an ingredient in house refuse. On account of the variable nature of house refuse, he had had several van loads (of about 3½ cube yards) weighed since the last meeting. The weight varied from 13 cwt. to 38 cwt. That proved how difficult it was to obtain reliable data as to the combustible properties of refuse.

Mr. J. N. SHOOLBRED said that he thought the estimate given in the paper of 1 lb. of water evaporated per lb. of refuse was a very fair one, taking all the circumstances into consideration; and he was glad to hear a statement of that kind made. Another matter which Mr. Baker had mentioned was, he thought, a very significant one. It was that with the escaping gases from the destructor they could scarcely hope to get steam at a pressure of more than 60 lb. per square inch. He thought that this might be explained, partly from the fact that a great deal of the high temperature which undoubtedly existed in the destructor was absorbed in the deflecting arch and in the flues; and also that heat was required in order to destroy the microbes and other germs of disease. The inability to raise steam to a higher pressure than 50 or 60 lb. by means of the escaping gases from the destructor, at once pointed to the use which should be made of the heat therefrom. It was thus made clear that the use of those escaping gases directly as fuel could not succeed in raising steam to 140 or 150 lb. pressure, which was now used in many engines, and especially in works for a supply of electrical energy. Still, even at those works, the escaping gases could be utilised somewhat in the way Mr. Baker had described for heating the feed water in the same mode that, more especially in the North of England, the waste steam and the smoke, after passing from the boiler, were made use of. By this means the heat from the destructors would aid very materially in raising the temperature of the feed water towards that required for the 140 or 150 lb. steam pressure. In fact, the assistance thus afforded would probably be more effective than by using the refuse directly as fuel.

Some persons seemed to think that electric lighting engineers were loth to take advantage of refuse destructors, but that was a most erroneous impression. In the majority of cases refuse destructors were so situated in outlying parts of towns that electric lighting engineers could not at present make use of them, owing to their distance from the electricity works, which were generally situated in the centres of towns. Electrical engineers would gladly, later on, avail themselves wherever possible of the assistance which refuse destructors could undoubtedly afford, as likewise that from water power. It should, however, be borne in mind, that this assistance would, at best, be of but an intermittent character. With town refuse destructors this irregularity in the amount of the escaping gases varied considerably, not merely with the season of the year, or with the day of the week, but also during each individual twenty-four hours. To attempt to overcome those hourly irregularities in the output some change was needed, so as to store the refuse, and thereby produce some uniformity in the rate of using the fuel throughout the twenty-four hours, or at least at the times when the gases were most needed. But it was only in large towns that the fuel could be so kept back.

Respecting the poor character of the house refuse in Halifax, as had been stated, owing to the reburning of the cinders in the kitchens, he must say that, from his own knowledge, the practise was by no means confined to Halifax. It largely prevailed in Leeds, Bradford, Huddersfield and in other towns in that part of Yorkshire. This statement as to the low calorific value of the refuse seemed to show that the estimate which had been brought forward in the paper of 1 lb. of refuse fuel per lb. of water evaporated was one upon which more reliance could be placed than upon many others giving a much higher calorific value, and which had of late been very frequently put forward. He should be glad if Mr. Baker would, in his reply, further explain his ingenious arrangement for heat storage—the more as several other speakers, besides himself, seemed to have failed fully to understand the verbal explanations which had already been given.

Mr. Penn Lewis said that at Richmond the great difficulty the board had to contend with was the objection which the inhabitants raised to the noxious fumes which were given off from the chimney of the destructor, and after a short experience an injunction was obtained and the destructor was itself destroyed. The governing body would not take up the subject again very readily, but he hoped they would do so ultimately, for they were losing very considerably financially from their present system. The house refuse was now all taken away by contract. Some thousands of tons were removed every year at a cost of about 3*s.* 10*d.* per ton. The road sweepings were made use of in another way. If means could be devised whereby the Richmond authorities could be enabled to once more establish a destructor without the nuisance of the last one the inhabitants would be greatly benefited. The destructor employed at Richmond was a small bee-hive one.

Mr. H. B. RANSOM referred to the statement taken from Mr. Jones's statistics, that at the larger towns using destructors with steam generators 6 horse-power per cell appeared to be the average result. At Southampton, where a very old type of cell had been used for six or seven years, they were getting from 6 cells 40 indicated horse-power from engines which he thought must consume at least 40 lb. of water per indicated horse-power hour. In some experiments which he made there with different pyrometers the gases appeared to be leaving the boilers at a temperature of 700° or 800° F. or more, and sometimes they reached 1000°. In that case at any rate the destructor gases were not used to their maximum capacity, and a great deal of valuable heat was unutilised. Mr. Manville had dealt with the supposed difficulty of getting high pressure steam, but he did not give any instances in which boilers working over destructors had raised steam at pressures above those mentioned by Mr. Baker. At Edinburgh the boilers raised steam continuously at 100 lb. pressure, and at several other places 60 lb. was considerably exceeded. In the abstract of the Warrington test, no reference was made to any dust which might have been collected in the flues. That was a very important matter as it meant a lot of cleaning and also a great deal of additional weight to be removed. He had seen it amount to 3 or 4 per cent. of the total, and at Warrington he understood the total amount of incombustible material in the refuse amounted to over 31 per cent. As to the system of storage which Mr. Baker had explained, it was clearly not a complete storage scheme. A certain amount of hot feed-water was prepared for the boilers during the heavy night loads. He supposed that that was all that the storage tank could do; but in addition to that there was an arrangement by means of which gases from the cells could be passed into the centre cell and over one cremator only. He presumed it was supposed that in that way the coal to be burnt on the cremator or secondary fire would be reduced by two-thirds, and only one-third of the steam would be raised or some proportion not necessarily one-third. He believed that view was a mistake, because the object of the secondary fire was primarily to raise the temperature of the gases, so that they would be harmless when they issued from the chimney. The refuse had to be burnt at a constant rate throughout the day; and the products of combustion remaining a constant quantity, the coal to be burnt in the secondary fire must remain a constant quantity. He did not see how the arrangement would save coal, or be equivalent to any system of storage, and without some such system destructors were practically useless for steam raising purposes on a large scale.

Mr. W. Schönheyder said that he failed to see why the fact that only 40 lb. or 60 lb. steam pressure could be obtained from the destructor, showed whether the destructor was good or bad. The lowness of the attainable pressure was not due to the destructor being bad, but was caused by more steam being taken out of the boiler than was produced. The only way in which the value of a destructor could be ascertained was to measure the amount of water which could be evaporated per lb. of fuel. He agreed with what Mr. Baker said as to the necessity of bringing the boiler near the place where the heat was produced, so as to prevent heat being lost. In the diagram the boiler had been brought considerably nearer to the fire than usual. Mr. Baker ought to go a step further, and take away the brick arch over the furnace, because it would necessarily burn away, and would do no good. Of course, the boiler must not be brought down too close to the furnace-bars, so that the products of combustion were cooled too much. The outlet for the products of combustion, as shown in the diagram, was much too near the raw material, and a large portion of the raw gases from the refuse would be taken away by the flues, thereby creating a nuisance. The opening for the escaping products ought to be much nearer the front door. The back part of the grate should do the duty of gradually heating up the stuff as it was brought down, and the highest possible temperature should be obtained in the front part of the grate. The material should be brought on to the fire along a sloping slide (as shown), but the speed at which it went forward ought to be under the control of the stoker. Light inflammable stuff ought to be brought forward quickly, and wet stuff ought to be brought forward slowly. That could be done by means of movable pushers or rocking-bars. He considered that the coal which it was necessary to burn when wet or poor stuff was coming down, should be burnt on the same grate as the other material. If the material was very wet, or without any carbon, it could not be burnt at all.

Mr. H. G. Assiter said that the paper and the discussion would be of special value, because the subject was one as to which it was difficult to obtain working data. He should like to hear some observations upon the burning or disposal of sewage sludge. That was one of the most difficult problems with which engineers had to deal. There was no doubt that, as chemists had stated, the most valuable properties of sewage were contained in the liquid portion, and that the solid residue had very little manurial value; their great aim, therefore, should be to dispose of the solid part as cheaply as possible.

Dr. S. Rideal, said that, as a chemist, he protested against the unsatisfactory nature of the majority of the figures which were given in reports on the efficiency of refuse destructors. The subject was a new one, and perhaps that was the reason why the methods for testing had not been put in a more satisfactory shape. Most of the experiments gave very little information as to the composition of the refuse tested, and many reports omitted data altogether as to the quantity of water present. That was the case with the statement which Mr. Baker had put forward with regard to the experiments at Warrington. There was no mention of the quantity of ash and water in the refuse. It was necessary, for the sake of comparison, that in all such trials some idea should be given of the amount of water present. With regard to the method by which the temperature of the gases was estimated, the copper wire test was absolutely valueless for the purpose of showing whether the cremators were doing their work or not. The copper wire test gave only a rough idea of the temperature at a particular instant, and no information as to the variation in the temperature. It was necessary that the gases should have a minimum temperature, and that they should never fall below the minimum temperature which would ensure their being ignited. It was also important to note, in connection with that, that a supply of a certain quantity of air to cause their proper oxidation was also essential. The copper wire gave no reliable information as to whether the cremator was actually cremating the whole of the gases. He should like to see the composition of the gases at that stage, so that he could tell whether they were oxidised or unoxidised, for it was well known that it was the unoxidised gases which gave off the odour and caused the nuisance. It was important to bear in mind the influence which the velocity of the gases had upon their final composition. He asked Mr. Baker for information as to the method by which the draught velocity could be accurately determined in passing through the cremator, as he was not aware of any satisfactory apparatus for the purpose.

Mr. F. H. Cheesewright said that the trial at the

Westminster Vestry Works had extended over six months. At the last meeting one speaker ridiculed the idea that the quality of the refuse in the poorer districts was worse in summer than it was in winter. Since then he had ascertained that during the summer months the Westminster refuse gave 25 per cent. of clinker, and that now it was giving a little over 15 per cent. The refuse used at Westminster was not screened or sorted in any way. He asked Mr. Baker whether any smoke, steam, or vapour emanated from the chimney stack in his district?

The President said that before calling upon Mr. Baker to reply, he would suggest that in future engineers who had destructors under their control should, for the benefit of their brother engineers and the advancement of the system, tabulate the chemical analysis of the refuse for, say, every week throughout the year, and publish the result, in addition to the evaporation of water they were able to effect. In Mr. Baker's destructor the use of a second furnace was not new, it was merely Mr. Jones's cremator placed in another position; the boiler was not new, but the arrangement, as a whole and as a combination, was undoubtedly new. He then asked Mr. Baker to reply upon the discussion.

Mr. Baker said that the great difficulty in elucidating the subject up to the present time was the want of information as to the evaporative power or calorific value of the refuse. He should have had very great difficulty in preparing the paper, if he had not had under his control a plant which was especially suitable for the burning of refuse. The Paddington breeze, fortunately, came to his hand during the coal strike last year, and from tests which he had made he had arrived at the conclusion that 1 lb. of water to 1 lb. of refuse was about correct and might be taken as a basis. When refuse was unsifted, dusty, and contained street sweepings, it was impossible to work satisfactorily with it, as the labour killed the whole thing. He was informed that the refuse used in the Livet tests at Halifax was remarkably good. There was no information given as to its component parts, it was simply stated to be screened refuse. It was so described in the *Electrical Review*, and he ventured to say that the boiler referred to in the paper would give as good results as the Livet system of setting. As to the steam pressure obtained in the various multitubular boilers which had been hitherto used in existing plants, of course, if they could have obtained a higher pressure than 40 lb., and maintained it for the work to be done, they would undoubtedly have used it. He believed that 40 lb. was the pressure at Southampton, also that the pressure was 68 lb. at Warrington. He was informed that the boiler was made for 100 lb., but it had never reached that working pressure. He was informed that at Leeds, the boiler was made for 100 lb., but that they had never obtained more than 50 lb. It would be a very great assistance, if engineers would give an actual analysis of the refuse as the President had suggested. It had been said that high temperature furnaces would burn out and give a great amount of trouble. Those engineers who were acquainted with boiler plate furnaces knew pretty well what the life of a high temperature furnace was. Even with a forced draught, the actual average temperature would not exceed 1500° or 1600°. He believed the Warrington test of 2000° was fallacious. He had tested, with a pyrometer, the gases even from a destructor with a crematory furnace and they did not exceed about 800° F. He took it, that under those circumstances, the wear and tear of a furnace with forced draught over and above one with ordinary draught would be worth incurring for the purpose of getting rid of the increased amount of material which the forced draught would accomplish. A high temperature was also undoubtedly required; and if they attempted to cremate the nitrogen and effluvia which were emitted without a high temperature, they might get into difficulties with their neighbours. That was the reason for suggesting that the combustion chamber of a boiler, being heated by a supplementary furnace, was the proper place to destroy these obnoxious gases.

With regard to the working pressure, it would be noticed in the paper that 140 lb. was the working pressure he had stated, that he had not taken any benefit from coal to be used in increasing the working pressure up to 140 lb. from that given by the refuse. Objection had been taken to his putting the boilers on the top of the destructors, and it was said that he would have to raise the material. Probably he would, but by using mechanical means he would be able to feed the furnaces with less labour; and he anticipated that he would have a sufficient quantity stored during the day to put in for the night, so that one man could look after the furnaces during the night. The space occupied by the combined destructor would be less than the space required where the destructor was in one battery, and the boilers in another. In London, the question of space claimed consideration.

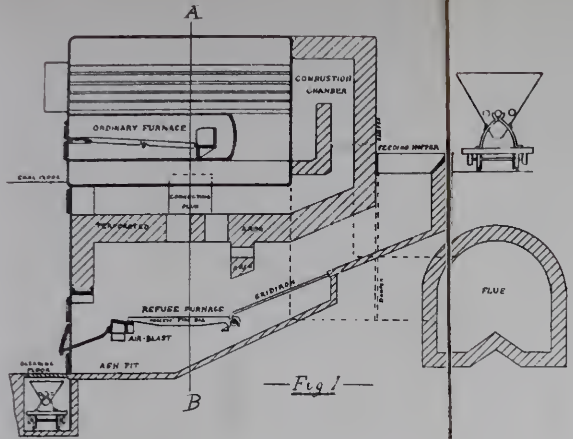
As regarded capital, Mr. Spinks would find in the paper an amount allowed for depreciation and sinking fund. The redemption was at 25 years' purchase, with interest according to the usual tables. The mechanical arrangements for feeding and cleaning had both been provided for in the estimates, and he arrangement of the furnaces in connection with the stoking vas a very great item in saving labour. 1*s.* 10*d.* was a full um for working cost and depreciation. In one of the northern owns, 1*s.* 3*d.* was stated to be the actual amount. A great leal had been said about the Warrington tests. He had imply reproduced the figures which had been given to him, nd he had no doubt of their accuracy. But if 2000° F. was o be obtained in the arch over the Warrington installation, it vas singular that only 68 lb. pressure could be reached.

He must refer to Dr. Rideal's remark, that the copper wire est was not the proper one to take. Exception had been taken o Lancashire boilers. There was no doubt that in a plain ancashire boiler without the cross tubes, a temperature exeeding 1500° could be maintained in the combustion chamber; ut a Lancashire boiler in which effective work was done in he flues, and which had a number of cross tubes in it, could ot be depended upon for cremating the gases from a refuse lestructor, and by the shorter form of boiler which he had uggested, they would get the extra heat which was absolutely ecessary to prevent the delivery of noxious vapours into the tmosphere. With regard to the heat storage system, he stated n his paper that the amount of his storage was equivalent to he value of the heat from two boilers or more that were used s stand-byes, and which took up the heat from the furnaces mmediately below them for the day load, and having a battery f 6 furnaces, 20,000 gallons of water raised from the normal o 212° F.; that would be going on all day, and they would be aking heat from it to feed the boiler as well as putting heat nto it and storing what they did not want. The great value, vhich had not been touched upon, was that they had two boilers r more always ready in case of fog or extra demand.

He was quite aware that sulphate of lime could not be taken way under 280° F. He proposed that the water should be put hrough a live steam feed-water heater. The separation would hen take place, but in it there would not be time for settling, ut the particles of the sulphate of lime and carbonate of lime vould have time to separate and precipitate out of the water n the storage tanks. He knew an instance in which that was lone. The water had 8° of hardness, which showed a large mount of sulphate of lime as well as carbonate, and the boiler n that case had worked very clean. His system of storage night not be theoretical, but he could aver that it was practially right. It could be seen at work in London. The weight f the column of return condensed water in the vertical pipe ad evidently not been taken into consideration by most of the peakers. No doubt an equilibrium was actually set up, but the weight of the water in the coil being slightly on the decline, the vertical column of water travelled down and found its way back, as a matter of gravitation, into the boiler. Mr. Glaskin's explanation as regarded the traversing of the gases in the boiler furnace was somewhat new to him.

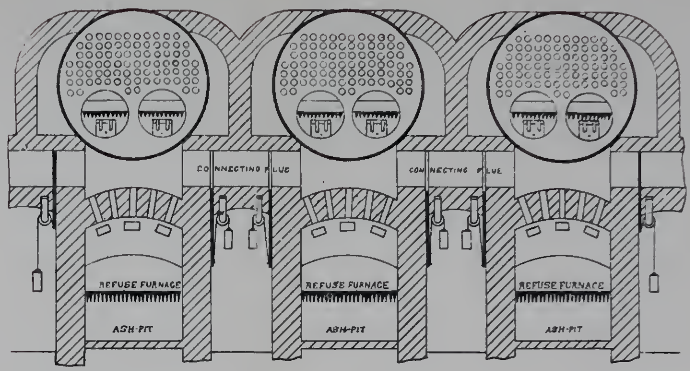
With regard to the dynamos, he had not, perhaps, provided for the losses. They must be taken into consideration, but he hoped to do away with them. The stand-by heat storage loss appeared to be comparatively small. He had allowed 30 per cent. during the light load, and 20 per cent. during the general load. One speaker considered that the whole power necessary for a large local authority could be absolutely generated without any coal whatever. He thought that, from the remarks which had been made, and from the criticisms on his paper, it would be seen that that was really not the opinion of gentlemen who had had very considerable experience. They believed that at some time or other they must call in the aid of coal. That, therefore, must be provided for. It could not be said that they could either store absolutely or depend wholly upon their refuse without the aid of coal, and that the plant should be capable of being worked with coal only. Several towns at the present time were objecting that effluvia came from the destructors, and he understood that one or two towns were actually ceasing to use their crematory arrangements, because of the cost of fuel. That showed that even with arched roof furnaces, there was a very considerable amount of effluvia, unless the extra fuel in the crematory furnace was used. He begged to thank the Society for the discussion that had taken place upon his paper.

Plate I



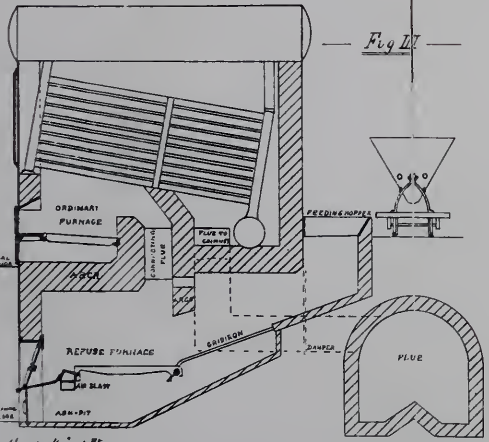
—Fig I—

Scale 1/8" = 1 Ft



—Fig II—

Scale 1/8" = 1 Ft



—Fig III—

Scale 1/8" = 1 Ft

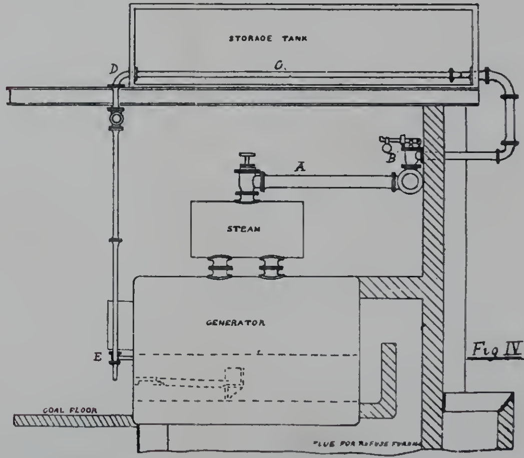


Fig IV

Scale 1/8" = 1 Ft

E. & F. N. Spon, London & New York.

December 3rd, 1894.

GEORGE A. GOODWIN, President, in the Chair.

THE PRINCIPLES AND PRACTICE OF HYDRO-EXTRACTION.

By Herbert Byrom Ransom.

The utilisation of centrifugal force is of great antiquity, but it is only since the invention of the steam engine that its practical usefulness has been generally recognised. Watt's pendulum governor for steam engines ranks among the earlier and better known efforts of inventors to utilise the radial acceleration which all rotating bodies possess, and it also forms a ready means of noticing how enormously this radial force increases in amount as the speed of rotation rises.

The special application of this force to the extraction of liquids from solids is now very general and probably dates back from a very early period. It is not very difficult to see why under centrifugal action a liquid should separate itself from a solid which it may be saturating. We know that if any body be moving in a straight line, it requires force to deflect it from its direction of motion. Thus a shot fired in the air will move steadily in a straight line until its course be deflected by external agency, which illustration embodies not only the substance of one of Newton's laws of motion, but may be proved experimentally in many ways.

Take a body moving along the arc of a circle, such as the bob of a pendulum. It is clear that the bob has motion, and also that its direction of motion is continually changing, and therefore that some force must be acting on it to produce this change in the direction of motion. The force, here imposed by the tension in the string attaching the bob to its centre of rotation, is called the centrifugal force of the ball. Were this force to be suddenly removed, or were the string cut, the body would not go on describing a circle, but would move steadily along in that direction in which it was moving just prior to the instant when the radial force was destroyed, and would continue in that direction until its course was modified by external agency.

Now, from the construction of the figure called the circle, it may be proved mathematically that the direction in which a body describing a circle is at any instant moving, is coincident with the tangent to the circle at that point. This law then tells us something more about what to expect if the string of a pendulum bob be cut, for now we know that the bob will move out in the direction of the tangent to the circle at the point at which the bob was when the string was cut. The knowledge of the fact is almost prehistoric, and its practical utility was recognised even in Biblical times in the application of the sling as an instrument of war.

The principles underlying the case of the pendulum bob are the same as those in operation when water is extracted from a sponge in a centrifugal machine. The solid sponge is prevented from flying out of the basket by the sides, so that these latter replace the functions of the string in the case of the pendulum. There is, however, nothing to prevent the escape of the water carried by the sponge, for the sides of the basket are perforated.

Although water has been taken as an example, it is perfectly clear that the same laws would apply whatever fluid had been held in saturation by the sponge, and further, not only can a fluid be extracted from a solid, but two different admixed fluids can be separated from each other by means of centrifugal force, provided they are of different specific gravities.

Thus cream may be separated from milk. If the milk be put on a rapidly rotating table (the axes of both coinciding in plan) the milk, being the heavier, will fly to the outer edges of the can, whereas the cream will collect in the centre, and can be drawn off by suitable appliances. This application of the centrifugal machine is not quite analogous to the case of the pendulum and bob. Perhaps the simplest explanation of the action may be obtained by considering the centrifugal force developed as a force acting, in this case, something like the force of gravity on a stationary mixture of the same two fluids. When the mixture is allowed to stand, the milk naturally falls to the bottom, because a force acts on the particles of each, which is proportional to their respective specific gravities. When the two fluids are in a rapidly revolving pan, centrifugal force acts in a similar manner, and consequently the molecules of milk force their way past the molecules of cream until they reach the circumference of the pan, and the cream is left by itself hemmed in at the centre.

From what has been stated it will be seen that the pressure exerted on the sides of a rotating basket by the material inside depends on the weight of the material, the speed, and diameter of the basket. The tension in a string attaching a revolving weight to the fixed centre of rotation, is equal to the mass of the ball multiplied by the square of its linear velocity and divided by the radius at which the ball is revolving. This statement may be expressed algebraically by the equation:

$$c = \frac{m\,v^2}{r},$$

where c = centrifugal force in lb. = tension in string;
m = mass of the weight = its weight in lb. divided by 32·2;
v = velocity of weight in feet per second;
r = radius of rotation or length of string in feet.

In a centrifugal machine the weight is replaced by the material which is to be dried, and the tension in the string is replaced by the restraining influence of the sides of the basket, and therefore the force c equals the total radial pressure on the sides. The material is generally assumed to be fairly distributed all round the circumference of the basket, and, therefore, its pressure on the walls is somewhat similar to that exerted by steam in a cylindrical boiler. Thus, in calculating the tension in the walls we may assume that one half of the basket is trying to tear itself away from the other half, and the resistance to this is supplied by twice the sectional area of the metal in the walls. This, however, is only true so long as the basket retains its absolutely circular form.

In estimating the stress in the walls of the basket due to materials alone, the safest rule is to find the centrifugal force which would be exerted by a body equal to half the weight of the material put into the basket, and to divide the result by twice the net sectional area of the sides, taking into account the loss of material by the perforations, &c. To find the total stress in the walls, the centrifugal force due to the weight of metal composing the walls themselves must also be allowed for. Examples of both these cases will be given later on, and therefore no more need be said at present.

It is almost needless to point out how important it is that the walls of the basket should be properly constructed, not only to meet the demands of a skilled user, but also to allow for unskilful handling. A badly constructed hydro-extractor may be safe, and even last for some years if the charges are arranged evenly around the circumference, but if the load be placed all on one side the result will probably be disastrous.

Another source of danger arises from the driving mechanism. Where a series of hydro-extractors are driven by belting from one large engine, every care must be taken to ensure the greatest possible regularity of running in the engine. Thus, even with a first-rate and expensive governor on the motor, the man in charge can simply, by a turn of the spanner on the governor-valve stuffing-box gland, cause the fluctuations in speed due to alterations in load to be doubled. The following example, taken by experiment from a well-known and widely used governor, may serve as a warning to purchasers of cheap hydro-extractors. In the case in point it was found that when the engine, running at 92 revolutions per minute, had half its load removed, its speed fluctuated 3 per cent. The man in charge thought the governor gland was leaking badly and therefore slightly tightened it. It was then found that the fluctuations in speed became as great as 7 per cent. when the same variation in load occurred. Had the engine been driving a series of centrifugal machines at 1200 revolutions per minute, then in the first case the centrifugal force would have increased 6 per cent., and in the second no less than 15 per cent. In another case, where it was afterwards ascertained that a little grit had got into the governor joints, the speed increased so much that the pressure on the walls of the basket would have increased 56 per cent., and that, too, within half-a-dozen revolutions of the engine, and when there had been no variation in load.

These illustrations are given to emphasise the importance of taking every care both in the choice of the machine and in its application and working. A bad machine or a careless user may give rise to an accident as serious as those arising from boiler explosions. It is indeed hardly ever realised that the bursting pressure in a centrifugal machine frequently exceeds that in the highest pressure boiler, and yet the latter is regularly inspected and, if necessary, repaired, whereas the former is generally allowed to run unexamined from year's end to year's end. The inquiries into accidents with these machines have almost invariably elicited the fact that in all those cases where the machines had been subject to fair usage, due examination would in all probability have averted the misfortune.

In order that users of centrifugal machines may fully appreciate the enormous force with which they are dealing, Table I. and a diagram showing the amount of these forces per pound of rotating material are given, and from them it can be seen at a glance what centrifugal force is being exerted in the machine, provided the weight of the material being dried and the diameter and speed of the basket are known. Thus, supposing 100 lb. of yarn is in a 4-foot basket running at 2000 revolutions per minute, it is only necessary to run the eye down the column headed 2000 until the line referring to baskets of 4 feet diameter is reached, and to make a note of the figures at the junction. In this case the figure is 2724 lb. per lb. of material in the basket, and therefore the total centrifugal force due to the load only would be 272,400 lb., and the basket would probably burst. To give another illustration: take a mass of iron 1 lb. in weight, and hang it by a string 1 foot long, when the tension in the string would be 1 lb. Next swing the mass round and round in a circle of 1 foot radius, say 300 times a minute. From the table it will be seen that the centrifugal force is 30·6 lb., and the tension in the string must be the same. In other words, the tension in the string has been increased thirtyfold, for no other reason than that the weight is in motion.

It should also be noticed how much greater is the effect of the number of revolutions per minute of the weight on the centrifugal force, than is the diameter of the basket. The centrifugal force of 1 lb. rotating 100 times per minute at a radius of 6 inches is 1·7 lb., while it is 3·4 lb. at 12 inches radius. But if the number of revolutions per minute be doubled instead of the diameter, then the centrifugal force increases from 1·7 lb. to 6·8 lb.—that is, as the square of the velocity. In other words, the angular velocity is a very much more important factor than the diameter of the basket when the safety has to be taken into consideration. It also affects the drying or liquid-extracting power to the same remarkable extent. This point is brought out more clearly by the parabolic curves in the diagram. It follows from this, that in the case of a wheel the speed might become sufficiently great to burst it into fragments without the aid of any other force.

Table II. gives the speed in revolutions per minute at which a basket of any size made of unperforated sheet metal would burst if unloaded. In practice, it is hardly necessary to state, the sides of a basket are hardly ever solid, but are nearly always weakened by perforations to allow liquids to escape. Machines are also not run unloaded, so that a load, whatever it might be, would increase the stress in the basket by an amount exactly proportional to its own centrifugal force. Thus, supposing 100 lb. of wet yarn to be distributed in a 4-foot basket, 20 inches deep, $\frac{1}{8}$-inch plate, making 1000 revolutions per minute:

The centrifugal force due to the yarn only = 68,100 lb.
The weight of the basket sides, if of iron = 120·6 lb.

The centrifugal force of 120·6 lb. under these conditions is 82,100 lb.

Therefore, the total centrifugal force which the walls of the basket have to withstand = 68,100 + 82,160 lb.
= 150,260 lb.;

or on a semi-circumference the total pressure = 75,130 lb., and the area of metal to withstand this = 2 × 20 × $\frac{1}{8}$ square inches,
= 5 square inches;

therefore, the stress per square inch $= \frac{75130}{5}$ lb. = 15,026 lb.

The breaking load of iron is about 45,000 lb. per square inch, and therefore in this case the basket is stressed only to $\frac{1}{3}$ of its ultimate strength, and the factor of safety would be 3. (If it be assumed that the material acts in a precisely similar manner to steam in a boiler, then 75,130 lb. becomes reduced in ratio $\frac{2}{\pi}$ and the factor of safety is increased in ratio $\frac{\pi}{2}$. This remark applies similarly to the figures given in Table II.)

Referring to the table of bursting speeds it should be noticed that if steel be substituted for iron, the bursting speed —or, as the Germans happily term it, the "explosion speed"— is 20 per cent. higher, but with copper it is 23 per cent. lower. Clearly, except for special purposes, steel should be always adopted. And for any other material the following rule holds good for baskets of the same general design.

Bursting speed of basket of any other material A = bursting speed of same sized iron basket $\times \sqrt{\frac{T}{W}} \times \frac{1}{8 \cdot 45}$; where T = tensile strength of material A in tons per square inch and W = weight of 1 cubic inch of A in lb.

Reference has already been made to the weakening effect of perforations in the basket walls; to ensure efficient working these perforations have to be as numerous as possible, but, to ensure strength, they should be as few and as small as possible. Hence a happy mean has to be struck in deciding the number of perforations, and their symmetrical arrangement, so as not to create a weak section, requires the greatest care. Even in the best designs it is frequently found that the basket loses 20 per cent. by perforations.

Another great disadvantage in the plate type of basket is that there must be a joint. The joint may be riveted doubly or singly, it may be welded, or, in the case of copper, it may be brazed. A single riveted joint has not more than 56 per cent. of the strength of the plate, and double riveting only raises this figure to 75 per cent. In addition to this, the walls must be thickened at the joint by the lay or butt strip, and consequently the basket is not in itself properly balanced, and it is the neglect of details such as this which has caused the centrifugal machine to be associated, in the minds of many, with great vibration. A welded or brazed joint depends largely on the skill or conscience of the particular workman who may happen to have the job in hand. Even with the greatest care either of these joints is at least 20 per cent. weaker than the solid plate, and this detail alone means that the basket as a whole must be made 20 per cent. heavier than is necessary for the work it has to do. All these facts point to one conclusion, namely, that the perfect basket should be of homogeneous construction and have no joints. It should also be made of some material stronger even than steel plate, and there should be no holes or perforations made in it by a tool; for any break in the surface skin of a metal is commonly suspected of weakening it beyond the loss of strength due to the decrease of sectional area of the plate.

These difficulties, however, can be overcome by the substitution of steel wire for the plate, the wire being wrapped round and round in a helix, having a space left between each wire for the escape of the ejected liquor.

Wire can be obtained in sufficient length to wrap round the largest basket without a joint for the whole of its depth, and no holes have to be drilled as is the case in the plate basket.

The strength of steel wire has been found to be from $2\frac{1}{2}$ to 3 times greater than good steel plate, and it is therefore eminently suitable for this purpose. When corrosive liquids have to be extracted, drawn copper wire, tinned, should be adopted. For the purpose of comparing the strengths of the two kinds of basket the following cases are taken.

To find the factor of safety in a 3-foot basket 18 inches deep, revolving at 1000 turns per minute, and loaded with 100 lb. of wet material. First take the basket made of steel wire 0·165 inches diameter, wrapped so that a space of 0·11 inches is left between each turn of wire (1 foot wire = 0·0715 lb.).

There are 65·45 rows of wire in 18 inches, and the circumference = 9·42 feet.

$$\therefore \text{ Total weight of wire} = (9{\cdot}42 \times 65{\cdot}45 \times 0{\cdot}0715) \text{ lb.}$$
$$= 44{\cdot}1 \text{ lb.}$$

$$\text{Centrifugal force of } \tfrac{1}{2} \text{ basket} = 22{\cdot}05 \times 510{\cdot}8 = 11{,}265{\cdot}0 \text{ lb.}$$
$$\text{,, \quad ,, \quad } \tfrac{1}{2} \text{ load} = \quad 25{,}540{\cdot}0 \text{ lb.}$$

$$\tfrac{1}{2} \text{ Total cent. force} = 36{,}805 \text{ lb.}$$

The sectional area of wire to meet this—

$$= 2 \times 65{\cdot}45 \times 0{\cdot}165 \times 0{\cdot}165 \times 0{\cdot}785 \text{ square inches.}$$
$$= 2{\cdot}798 \text{ square inches.}$$

Taking the ultimate strength of the wire at 75 tons or 168,000 lb. per square inch we get the factor of safety

$$= \frac{2{\cdot}798 \times 168{,}000}{36{,}805} = 12{\cdot}77.$$

Had the basket been made of iron plate 0·165 inches thick, welded, after deducting 30 per cent. of the strength to allow for weld and perforations, it will be found that the factor of safety is only 3·83 under the same conditions. Had the plate been 0·33 inches thick the factor of safety would only have been increased 35 per cent. By comparing the factor of safety for the wire basket (12·77) with that for the plate basket (3·83) it will be seen that the former is 3·39 times as strong as the latter. It should also be noted that the relative proportion of these two factors of safety remains unchanged be they each increased in ratio $\frac{\pi}{2}$ or not. The reasons for this are that (1) Wire is at least $2\frac{1}{2}$ times as strong in tension as plate; (2) The wire basket is lighter because the area through which the liquor escapes is far greater than the perforated area in the plate; (3) No reduction in the strength of the wire basket is caused by perforations or welding. It is by no means an uncommon thing to find a factor of safety of only three in a basket, and if this be sufficient, then it is quite clear that it would be perfectly safe to place from three or four times as great a load in the wire basket as in the plate basket.

It may be interesting, for purposes of comparison, to give the usual factors of safety adopted in steam boilers. Marine boilers are nearly always built in accordance with the instructions of the Board of Trade or Lloyd's. The directions of the Board of Trade are that if the fullest inspection be allowed by their officials during construction, and if the most elaborate precautions are taken to ensure the very best possible workmanship and material, then they may allow the metal to be stressed up to $\frac{1}{5}$ of the breaking load; but if these instructions be not complied with, then it is not unusual for the officials to refuse to pass the boiler unless the factor of safety is as high as 10.

As has already been stated, it is not unusual for factors of safety in centrifugals to fall as low as $2\frac{1}{2}$ or 3, and yet the Board of Trade decline to consider a boiler safe unless its factor lies between 5 and 10, although the latter is stationary and equally stressed, while the former is in motion and its speed reaches the highest that it is possible for any machine to attain to, and is frequently subject to the caprice or whim of untrained attendants.

Enough has now been said as to the best construction of a centrifugal basket, but the user is frequently in doubt as to what class of basket will best suit the work he has to do. The solution of this problem has frequently to be obtained by experiment, but a few general observations may nevertheless be of some use. Some materials are what is termed very sticky (that is to say, water can only be extracted with great difficulty); and the more sticky the material the greater the centrifugal force necessary for the extraction of the moisture. A high centrifugal force is best obtained by a high angular velocity, and as may be seen from the bursting speed table, only baskets of small diameter can be used at very high speeds with safety. Hence it is customary to dry very sticky materials in baskets of small diameter only.

A curious, although perhaps not unnatural property, possessed by some materials, is that a very large proportion of the total moisture they contain is thrown off while the machine is still increasing its speed. This, of course, eases the basket considerably, and should always be taken advantage of when possible by allowing the speed to reach its maximum by stages. And in this way the material to be dried may sometimes be reduced in weight 50 per cent. before full speed is reached, reducing, consequently, the tension in the basket by nearly the same amount. Hence a proportionately larger load may be treated at one operation with as great safety as if the speed had been suddenly acquired with a lighter load. No doubt this peculiarity is emphasised, as the difference between the specific gravities of the material to be dried and the liquor extracted, becomes greater. Table III., giving the specific gravities of a number of liquids and solids, may be of service in considering this question. Distilled water at 39° F. is taken as the unit.

Although hitherto only the construction and suitability of the basket have been dealt with, a very important item, namely, the means of driving the basket, has still to be considered. The basket itself is usually mounted upon a vertical spindle, which is free to rotate, but is prevented from having any lateral motions by very carefully fitted bearings, one of which is a pivot. This shaft may be caused to rotate either by a belt and pulley, or by constructing it in such a way that it is itself the crankshaft of a small steam engine. Belt-driven machines are frequently adopted in large establishments where a number of centrifugals or other machines are in use, as it is then more economical to drive the whole by one large engine. Self-driven machines are often convenient for placing in isolated portions of large buildings, or in small establishments, or for intermittent use. The commonest form of self-driven machine is that in which the engine is placed under the machine, and acts directly on the shaft to which the basket is fixed. There are many modifications of this engine, but for the present purpose it will be quite sufficient to consider one type only. The basket of a centrifugal machine not unfrequently makes 1200 revolutions per minute, and therefore the piston rod and cross-head must move outwards and inwards 2400 times per minute. The author will assume, for the sake of example, that the stroke of the engine is 12 inches, and that the weight of these parts is 30 lb. It is not easy to realise what it means to move such a mass from rest, through 12 inches, and stop it again, some 2400 times a minute. It is perfectly clear that this weight of metal must exercise an immense retarding influence on the engine at the start, and it will tend to push it onwards towards the end of its stroke while being stopped. In this case the actual force necessary merely to start the piston rod and cross-head alone would amount to 7684 lb. The steam pressure is, of course, not nearly enough to avert this force, for with an 8-inch diameter cylinder and 50 lb. pressure per square inch, the total effort only amounts to 2500 lb. The basket, however, goes on turning, for it supplies by its own momentum the unavoidable deficit of steam power. Suppose the rim alone of a 3-foot basket to weigh 50 lb.; then to bring it to rest in one-ninth of a turn when it is making 1200 revolutions per minute, a force of no less than 91,680 lb. would have to be applied at the crank pin.

Clearly, then, the momentum of the basket should be sufficient to start the piston, &c. But it must be noticed that the crank pin is not attached directly to the cross-head, and this force of 7684 lb. has to be transmitted to it through the connecting rod.

This is a point which is sometimes neglected in the design of such high speed engines, and the rods are proportioned to stand the steam pressure only of 2500 lb., whereas they are constantly subjected to a load of more than three times that amount. It should be observed that this great tension in the connecting rod only occurs temporarily at the commencement or the end of the stroke, that is, at such times as the connecting rod is in line with the crank. The rod is either pulling or pushing the crank pin, and the force is transmitted thence through the crank almost directly on to the main bearings supporting the crank shaft or spindle of the basket. Thus, unless special precautions are taken to obviate it, a perpetual series of blows is being rapidly struck on the basket spindle, first on one side and then on the other, and this is an important cause of the vibratory motion which so frequently pervades the surroundings of badly designed machines.

The difficulty can be got over in practice in two ways. Firstly, the effect of the blows can be minimised by arranging other equal and opposite forces to act simultaneously on the shaft, and secondly, the engine, basket and guard pan should not be secured to the floor, but the whole should be attached to the foundations by some non-rigid contrivance. It is not an unusual thing to suspend the whole machine from uprights attached to the floor, allowing it to swing freely. There are also many other similar arrangements, but all are such that they permit of free oscillations within certain fixed limits, thus diverting from the foundations the vigour of the blows which are continuously delivered by the reciprocating parts of the engine.

It must not, however, be supposed that the piston, &c., is the only portion of the engine which needs balancing in a high speed engine. The crank webs of the shaft are themselves turning at the same angular rate as the basket, and although their mean radius is not great, their weight is considerable.

In all cases these balance weights have to be applied with very great care and, although the crank webs only have been taken as an example, all such parts as eccentrics, connecting rod, &c., have to be accounted for in a similar manner. Numerous attempts have been made to carry these self-driven machines so as to obviate vibration, and sometimes with success, but in most cases the root of the evil is the engine itself.

When hydro-extractors are belt-driven, no doubt a great advantage is gained by the freedom from oscillation, for, as previously stated, the principal defects in a self-driven machine which cause vibration are those due to the engine and not to the basket, and therefore, if the engine be detached and run at a slow speed to drive the basket by belting, then the primary evil will be removed. There remains, of course, the danger that the attendant may load the basket all on one side and thus cause vibration, but this may be avoided by the adoption of ordinary precautions.

In conclusion, the author regrets he has not been able to go more into the details of construction of hydro-extractor engines, but he trusts that what he has stated will prove useful to the Members of the Society, and that a good discussion will ensue.

TABLE I.

CENTRIFUGAL FORCE IN POUNDS PER POUND OF MATERIAL.

Diameter in feet.	Speed of Rotation in Revolutions per Minute.																	
	100	200	300	400	500	600	700	800	900	1000	1100	1200	1400	1600	1800	2000	2500	3000
1·0	1·70	6·81	15·32	27·24	42·56	61·3	83·43	108·97	137·93	170·25	206·00	245·15	333·75	435·90	551·65	681·00	1064·00	1532·25
1·5	2·55	10·22	22·98	40·86	63·85	91·95	125·16	163·47	206·90	255·40	309·0	367·7	500·6	653·8	827·4	1021·6	1596·2	2298·8
2·0	3·41	13·63	30·65	54·49	85·13	122·60	166·87	217·95	275·86	340·50	412·0	490·3	667·5	871·8	1103·3	1362·0	2128·0	3064·5
2·5	4·26	17·03	38·31	68·56	106·42	153·26	208·60	272·42	314·80	425·60	514·9	612·9	834·4	1089·8	1379·0	1543·6	2660·2	3831·05
3·0	5·11	20·44	45·96	81·73	127·70	183·90	250·32	326·94	413·80	510·80	618·0	735·5	1001·3	1307·6	1654·9	2043·0	3192·0	4596·7
3·5	5·96	23·84	53·63	95·35	149·00	214·55	292·00	381·40	482·70	595·00	721·0	858·0	1168·2	1525·8	1931·0	2383·4	3724·0	5362·8
4·0	6·81	27·25	61·29	108·97	170·26	245·20	333·74	435·90	551·72	681·00	824·0	980·6	1335·0	1743·6	2206·6	2724·0	4256·0	6129·0
4·5	7·66	30·66	68·96	122·60	191·57	275·88	375·45	490·40	620·65	766·20	927·0	1103·3	1502·2	1961·5	2482·8	3065·0	4789·0	6897·0
5·0	8·51	34·06	76·61	137·12	212·84	306·52	417·20	544·84	689·60	852·00	1039·9	1235·8	1768·8	2179·6	2758·0	3087·2	5320·4	7602·1
5·5	9·36	37·47	84·28	149·85	234·13	337·16	458·90	599·40	758·70	936·40	1133·2	1348·5	1835·8	2397·7	3031·2	3745·5	5852·5	8127·8
6·0	10·21	40·88	91·94	163·45	255·39	367·80	500·61	653·85	837·58	1021·50	1236·0	1470·9	2002·5	2615·2	3309·9	4086·0	6384·0	9193·5

TABLE II.—BURSTING SPEEDS FOR PLATE METAL BASKETS OF THREE MATERIALS.

Diameter of Basket in feet.	Bursting Speed in Revolutions per Minute.		
	Iron.	Steel.	Copper.
1·0	9985	12011	7720
1·5	6656	8006	5147
2·0	4993	6005	3860
2·5	3994	4804	3088
3·0	3328	4003	2574
3·5	2853	3432	2206
4·0	2496	3002	1930
4·5	2219	2669	1716
5·0	1997	2402	1544
5·5	1816	2183	1404
6·0	1664	2002	1288

Note.—These figures should be all increased in ratio $\frac{\pi}{2}$ if it be assumed that the stress be similar to that obtaining in a cylindrical steam boiler.

TABLE III.—SPECIFIC GRAVITIES.

WATER	1	Sand, quartz	2·75
		Sand, river	1·88
Aluminium	2·67	Tallow	0·94
Copper, wire	8·9	Tar	1·20
Copper, sheet	8·78	Sea water	1·03
Iron, wrought	7·78	Acetic acid	1·05
Steel	8	Alcohol, absolute	0·792
Lead	11·36	Alcohol, proof	0·916
Mercury	13·59	Ether	0·716
Zinc	7	Hydrochloric acid	1·2
Tin, cast	7·29	Citric acid	1·22
Brass, wire	8·54	Oil, linseed	0·94
Brass, sheet	8·44	Oil, olive	0·915
Asphalt	2·5	Oil, whale	0·923
Cement, Portland	1·7	Sulphuric acid	1·84
Clay	1·9	Oil, sperm	0·88
Coal, anthracite	1·53	Oil, palm	0·90
Coal, Newcastle	1·27	Oil, neatsfoot	0·914
Coke	0·74	Oil, rapeseed	0·914
Concrete, ordinary	1·9	Oil, castor	0·966
Concrete, in cement	2·2	Blood, human	1·055
Earth	1·52–2	Skimmed milk of cow	1·034
Glass, flint	3·08	Cream, about	0·900
Glass, plate	2·76	Naphtha	0·848
Guttapercha	0·96	Vinegar	1·026
Gypsum	2·28	Wines, about	0·994
Indiarubber	0·93	Brandy	0·837
Ivory	1·82	Ash, wood	0·70
Lime, quick	0·84	Cork	0·24
Mortar, average	1·7	Pine, white	0·50
Pitch	1·15	Oak, English	0·85
Plumbago	2·27		

DISCUSSION.

The PRESIDENT said he was sure the meeting would pass a cordial vote of thanks to the author of the paper. The subject was a very interesting one, and he hoped it would lead to a good discussion. Before the discussion commenced, a communication from Mr. John Hudson, of Bolton, on the subject of the paper would be read.

The vote of thanks was unanimously accorded.

The following communication from Mr. Hudson was then read:—It is some years since I had to do with centrifugal machinery, but I still take an interest in it. I think the author has done well in calling attention to the danger attending the careless or unintelligent use of centrifugal machines, many fatal accidents having been caused by their bursting. As such failures may occur with the best designed machines, either from corrosion or overspeed, I am surprised at not finding any mention in the paper of the use of thick wrought-iron or steel boiler plate outer casings, capable of confining the fragments of a burst basket, such casings having been adopted for many years with the best results by the leading makers in this country, in place of the original casings of thin cast iron which are quite incapable of resisting the pieces of the basket, their own fragments merely adding to the number of deadly missiles.

The stress on the material of the basket is, no doubt, necessarily severe, and for practical reasons it cannot be materially reduced by increasing the thickness; but I would ask the author whether his method of calculation does not overestimate its amount. The stress on a circular hoop exposed to a bursting pressure is equal to the total centrifugal force, or other bursting load, divided by 6·28 times one section of the hoop, and this being so, the rule given in the paper, which corresponds with a divisor of four only, overestimates the stress on the material to the extent of 57 per cent. It is the same as taking the tension on the two sides of a boiler shell, as being equal to the pressure multiplied by the semi-circumference, instead of by the diameter. Again, the author calculates the bursting effort of the charge as though each particle of it was at the full radius of the basket shell; whereas the charge would form a wall some inches in thickness, the effective radius of which for calculating the centrifugal force would be

$$\sqrt[2]{\frac{\text{outer radius}^2 + \text{inner radius}^2}{2}}.$$

The author seems to indicate that machines are still being made to run in rigid bearings, and makes only casual mention of an improvement introduced by an American, Mr. Weston, some years ago, which may be said to have revolutionised the manufacture. I refer to the principle of supporting the basket spindle in one yielding or elastic bearing, in place of two rigid ones, so as to allow an unbalanced or eccentrically loaded basket to revolve about its centre of gravity, instead of about its geometrical centre. The resulting saving in wear and tear is enormous, and a machine so fitted may be run on a light garret floor if necessary, whilst the fixed type of machines require a heavy foundation and cause great vibration.

As regards the merits of wire and solid plate for forming the outer wall of the basket, the theoretical advantage, no doubt, lies with the former; but in practice there is difficulty in obtaining the necessary rigidity, and the vertical and diagonal members introduced for the purpose, and the solder securing them to the wire, all add weight without doing useful work. Baskets of this type are liable to come adrift and resolve themselves into loose coils of wire. The solid plate seems to be the more practical construction, it is one and indivisible, cheaper to make, and more easily cleaned, and every part does its share of the work. The joint, usually riveted, is no serious detriment, and with a little care the section at this point may be made nearly equal to the section through the perforations, and after some corrosion the joint will probably be the strongest part. The extra weight of the joint must of course be balanced either by a second and opposite joint, or by a strip of equal weight riveted to the basket.

Mr. Arthur Rigg said that he agreed with the opinion which had just been read, that the simplest plan for getting over the difficulty of an unbalanced basket was to let it run in a free bearing, so that it should turn around the centre of gravity instead of its geometrical centre. He saw a machine in America arranged in that way ten years ago. With regard to the steady driving of centrifugal machines direct, it was the old story that if they wanted an engine to run at a steady speed, it was necessary to provide a good governor. The proper principles on which such governors should be constructed were perfectly well known. He had looked up some old drawings, and found some which might be of interest. One illustrated an arrangement designed many years ago to drive centrifugal machines each by its own engine direct. These drawings were dated 1867. At that time he was met on all hands by the puerile objection that it was utterly impossible to run any engine over 200 revolutions a minute, a very absurd opinion considered in the light of present knowledge. Things had now gone to the opposite extreme, every small engineer throughout the country advertising engines to run at any speed desired. In any centrifugal machine driven by an engine direct there were two things which had to be balanced. One was the basket, and the other the engine. If the material, whatever it was, could be distributed in the basket fairly uniformly, it would not be very far out of balance. He was glad to hear that these machines seemed to be having various improvements made in them, which certainly were not made before they were wanted.

Mr. W. SCHÖNHEYDER, referring to Mr. Hudson's communication, said that it seemed rather curious that the author should make an error in his calculations, but it seemed, according to the paper, that it was the custom (he supposed that it was an old custom) to estimate the centrifugal force by taking half the weight of the revolving parts instead of taking the weight divided by 3·14. He thought that in the tables which appeared at the end of the paper some reference should be made to this, because the first table gave the centrifugal force of a revolving body, he believed correctly enough, but the second table gave the centrifugal force in bursting revolutions of the basket on the supposition that it was correct to divide the weight by two, instead of by 3·14. Either the table should be corrected, or else it should be stated that it was calculated on that supposition. For instance, take the first example, that of a wrought-iron basket, the bursting speed was given at 9900 revolutions a minute. It should be 12,500, or thereabouts He wished to know whether the machine had ever been supported in elastic bearings, so as to make the basket balance itself.. That had been done for a long time in various milk-separating machines by Laval. In his latest steam turbine he mounted it on a perfectly flexible shaft, and whatever unbalanced weight there was in the machine set itself right. I would be interesting to know whether the author had ever tried the machines for separating oil from water. That was very necessary before returning the water of condensation to a steam boiler. It was rather a difficult thing to do.

Mr. J. B. ALLIOTT said they had a very interesting communication from Mr. Hudson, but it was a little remarkable that a gentleman who had such a considerable knowledge o hydro-extractors, should have supposed that the idea of carrying a centrifugal machine in a single suspended bearing, and permitting it to gyrate like a revolving pendulum unti brought back to a central position, should have originated in America. Early in the forties machines were made which had their bottom bearing capable of yielding to uneven strains in the basket and of performing a gyration. Strictly speaking those were not suspended baskets; but between 1850 and 1860, machines which were as truly suspended as those of which Mr. Hudson spoke, and having no bottom bearing, were made and had been working continuously almost ever since both in India and in England. Mention had been made of the centrifugal machine as used for the separation of cream from milk. That had been used on a considerable scale only in comparatively recent times; but the application of an imperforate centrifugal machine for that particular purpose was made fully thirty years ago by the late Mr. Harrison, for many years one of the inspectors under the Local Government Board, and, as worked by him, it was perfectly successful. It had been said that a plate basket might be made of sufficient strength to stand the strain communicated to it by centrifugal force, and that was quite true; but if so made, not only must it be heavier than a wire basket, but if it gave way from any cause it gave way suddenly and entirely, and in fact, burst. It was a very rare thing for a wire basket to burst in the same sense; but if it gave way at all, all that happened would probably be the displacement or the elongation of a few wires without any such disastrous effects as were produced by the bursting of a plate basket. When plate baskets began to be extensively used without sufficient precautions against bursting being taken, casings so made as to stand the bursting of the baskets without being themselves destroyed became a necessity, and when a certain number of plate baskets had burst with disastrous results, such casings were introduced. Previously no one had felt the need of them.

One of the evils arising from the balancing of a plate basket n the method suggested by Mr. Hudson was that, whilst the additional thickness arising from the riveted joint on one side of the basket might be counterbalanced by a piece of plate on the other side, the strain upon the basket was not equalised by the same means. The tendency of the two weights on opposite sides was to make the basket oval, and the result was to throw undue strains of other kinds upon it. The question had been asked whether centrifugal baskets had been carried in elastic bearings. That was frequently done; and, in addition to that, n many instances balance weights had been arranged upon the shaft; and if the basket began to gyrate, and not to turn truly about the centre corresponding with the centre of its spindle, he weights changed their position and brought it back to the rue centre.

The application of a direct engine for the purpose of driving an extractor took place at a very early period of the history of he centrifugal machine. One arrangement consisted of a steam turbine, the shaft of the turbine being also the shaft of the centrifugal cylinder. In those days, however, steam turbines had not been brought to the perfection they had recently attained. The record of the arrangement might be found in the Patent Office, but he did not think that it ever became a commercial success. The use of high-speed engines for driving centrifugals directly had had very considerable extension, and probably there were more reciprocating engines running at very great speeds, for the purpose of driving extractors, than for any other purpose. A few months since reference was made to the possibility of cutting off the strains which ordinary engines communicated to their foundations by suspending them, and the idea was looked upon as an entirely new one. But the fact wa that high-speed engines driving centrifugal machines had been cut off from their foundations by sliding or yielding support for a considerable number of years; and that means had been proved to perfectly meet the purpose for which it was adopted namely, the cutting off of the vibration.

Mr. J. M. C. Paton said that one of his first recollections o his apprenticeship, some 26 or 27 years ago, was that of seeing a hydro-extractor suspended from a roof. Instead of the foundation bolts going down and taking hold of the ground they went up and took hold of the ceiling; and the machine was being driven by a self-acting engine which was being run to death. The title of the paper included the practice of hydro extraction, but they had not heard anything upon that point There was room for information with regard to the various type of machines which were made, the percentage of moisture lef in the goods, and the speeds best suited for various kinds o materials. Many practical points arose in considering what wa the proper charge to put in a machine at one time. There was as yet, no perfect self-discharging centrifugal machine, and in that respect there was a point still open to inventors. Some materials were sufficiently dried and ready for taking out a soon as the speed got up to 1000 or 1200 revolutions pe minute; but there was an immense loss of power and of time in stopping the machine under such circumstances. There wer several self-discharging machines which worked with more o less success on particular materials, and at particular speed for certain materials, but there was nothing which could be applied to general use. A satisfactory invention would be very valuable. The strains on the basket of a centrifugal machine were not merely bursting strains, but, when materials were pu in in lumps, as they were sometimes in chemical works, it wa clear that there could be no balancing of the load, and the strains brought on the machine were enormous. There would be cross strains, as well as centrifugal ones, and those had to be provided for as well as bursting strains.

What Mr. Alliott had said about wire baskets was very rue. Wire baskets always seemed to him (the speaker) to be he safest. They gave notice if they were going to burst. They vent to pieces gradually, and only required the most casual xamination. It was otherwise with plate baskets. With egard to high-speed engines there was an immense number of hem running hydro-extractors, and making 1000 or 1200 evolutions per minute, and they went on year after year; but ne point to be observed was that they were stopped frequently, nd oil was put in. If they were set to run day and night for week there would be very little left of them. When they roke down they did so very badly, and there was only a bagul of pieces. There were various types of machines with penings below for discharging, but there was room for improvement there. Most of the material was put in at the top, nd taken out in the same way; but that was wrong. When he material was once in the basket, it ought to continue to escend and be discharged by gravity. With regard to plate askets, he had seen many of them working with very small actors of safety. Such baskets were usually reinforced by iron ands either put on tightly or shrunk on. Such baskets would e found barrel-shaped between the rings, having been stretched ar beyond their limit of elasticity, and yet they went on orking in that condition for years. He remembered seeing centrifugal machine for drying grains, and he thought that it as a promising machine, but it had disappeared. It was in orm something like two tea saucers which approached each ther at the lips. When the machine revolved the water ran ut between the lips. The two saucers were mounted on a ollow shaft, and the grains could be fed up the shaft, the aucers separated, and the contents discharged at the circumerence without the machine being stopped. Materials which ormed a pasty mass in the machine were very difficult to deal ith. A few years ago a patent was taken out for perforating he top and bottom of the basket, so that the water went ut in that direction. That, however, was a very old arrangement.

The author had spoken of the spindle of the machine as if was always vertical. Many machines had been made with orizontal spindles, and were mounted somewhat in the form f a grindstone. When they were fed with material of about he consistency of mortar, the charge distributed itself equally ound the machine. When the machine was stopped by means f the brake, the whole of the contents dropped down to the ower side and could be simply shovelled out, and need not be craped. As to the methods of driving, it had always seemed o him that in the case of machines consisting entirely of revolving parts there ought, in a combined driving apparatus, to be no reciprocating parts whatever; and that opened up at once the question of electric motors. A number of machines had now been fitted up with electric motors placed directly on spindles, and those with which he had been concerned had worked excellently. One point to be considered was that the motors should be arranged in such a way that speed could be got up quickly. That was a great point. He believed that in a few years they would hear a great deal more of electric driving. As to the number of holes in the periphery of a machine, the difference in the ideas of users was very extraordinary. He had seen some machines with about 150 holes, and others with over 9000 in baskets of the same size.

Mr. T. W. Baker said that, looking at the subject rather from the point of view of the user than that of the constructor, he should like to have some further information. When he had met with users of machines of the class under consideration the first question they had asked of him had been, Which sort do you advise me to have, an over-driven or an under-driven? He thought that they ought to have some light thrown upon that point An elastic journal had also been mentioned. A description of that would be desirable because generally it was with regard to that point that the user found his great trouble.

Mr. J. Laidlaw said that the theoretical principles and conditions pertaining to centrifugal action, which occupied the greater part of the paper, were very simple and well known and might be accepted without investigation. It was comparatively easy for any one who possesed a correct knowledge of scientific principles to state the conditions of construction of a machine as they ought to be; but unfortunately the mechanical engineer was limited in the selection of the material available for constructive purposes, and while perceiving the form which would be scientifically correct had often to make modifications in design in order that his machine might be better adapted for its purposes. A steel wire might be stronger than a steel plate, but it did not follow that steel wire was therefore a better material for the construction of a centrifugal basket. The author had assumed, in calculating the strength of the basket shell, that it was necessary that the basket must remain absolutely circular but it was to be regretted that he had not shown how a wire helix could be made to retain its cylindrical form, instead of disposing of that important detail in a few lines. To make a centrifugal basket shell out of a helix of wire and yet have it absolutely circular and stiff enough to remain circular when revolving at a high speed and carrying a varying load, would probably be found more difficult than the author imagined. If he (Mr. Laidlaw was correct in assuming that the author approved of the wire basket of the days of slow speeds and light loads he could only say that he was very much surprised. Should there be any improved construction in the author's mind, it was to be regretted that he had not shown a drawing to illustrate his design, Nevertheless the wire helix must be held together and secured to the bottom and top rings and there must also be some means of preventing the helix from stretching vertically. When drying such material as sugar the pressure on the top ring, and the bottom, at least at the circumference, was practically the same per square inch as on the shell itself, owing to hydrostatic pressure. That involved vertical ties sufficient to take the whole strain, because the helix if left to itself would open out like the spring of a pop-gun. Then there must be diagonal braces to prevent twisting; and if all this constructive detail was properly done the weight of the basket would actually be greater than a perforated steel plate basket corresponding in stiffness and capacity. Steel could be got of a much higher tensile strength than what was stated in the paper. Further, the steel plate shell could be made as round as if it was turned; but the wire basket shell could not. In a basket, say 3 feet deep, made of wire, the elasticity would be so great that in a short time it would twist like a corkscrew. On the other hand a steel plate basket would remain stiff and true. He had never seen a wire basket which was perfectly true after a few months' full work; and very seldom a quite circular one before commencing work. Apart from the weakness in the construction of a wire basket the projecting ties with braces on the outside increased the power required to run it owing to the fan action which they set up. That was a very important point which perhaps had not received sufficient attention. After the inertia of the load had been overcome there was nothing further to be overcome but the friction of the bearing and the resistance of the air. In the drying of textile material a large amount of air went through to carry off the moisture.

His earliest mechanical experience was associated with the repair of wire extractor cages, which after a comparatively short period of use required constant attention. He had known many cases in which the repair of wire cages had caused so much trouble and expense that the wire baskets had been replaced by steel plate baskets with the best results. It appeared to him very extraordinary that nowadays any one could be found to say that in the interest of the user a wire basket was the best construction. There were many steel plate baskets 48 inches in diameter, running at from 800 to 1000 revolutions per minute and carrying a discharging load of from 700 to 800 lb. and in perfect order. Of course hydro-extractors or machines used only for laundry or other textile work did not require to carry a heavy load; perhaps not more, in a 48-inch basket, than 250 lb.; but there were steel plate baskets which had been in regular use for thirty years for textile goods that had never been repaired, and if they were put in the lathe they would be found to run quite true and circular. He doubted very much whether the same could be said of any wire basket. Since there must be perforations in the shell the same strength of shell could always be obtained as in the riveted joint. Any mechanic knew how to balance a cylinder made of plate as well as one made of wire. Both must be balanced, as the stays and solder of a wire basket could not be put on with uniformity to dispense with a balance piece.

He agreed with the remarks which had been made concerning inspection. Something ought to be done to secure proper inspection of dangerous machines. Attention had long ago been directed to that point. Inspection should be made at least twice a year. He could bear out the remark which had been made about plate machines. He had seen a plate basket which was intact after having worked for fifteen or twenty years, though the shell in the lower part was not thicker than a sixpence.

After many experiments, and a considerable amount of investigation, he had found that belt driving, if properly designed, either from a line shaft, or from the fly-wheel of an engine, would give better results than the engine working direct on the basket spindle: the results being measured by the cost of repairs, the power required, and the amount of work done. An extractor engine, like all other engines, must be designed for its special work. The governor should be made so that a stuffing gland was not necessary, and if the engine exceeded its speed, it should be stopped by the action of the governor.

Mr. E. TAYLOR said that for thirty years he had been dealing in centrifugal machines, and the most satisfactory machine in the market was that with a plate basket, made either of copper or steel. He confirmed Mr. Alliott's statement, that machines driven with a direct engine had been in use for at least fifteen years. Within a short distance from the meeting hall he had three or four in use, which had been working satisfactorily for over ten years with an engine attached. With regard to the strength of the material, it had been a common practice to put hoops round the outside to strengthen the machines, and also to use wire in the same way. He thought that practice would meet the author's views with regard to strength. He had had many made of copper, with a wire arrangement outside, to prevent serious accident in case of the copper failing. He should have liked to have heard more about the movable spindle, as the Americans were making it. There was no doubt that was general just now. English makers should adopt the same system. They were very slow to do so, and the consequence was that the Americans were flooding the market with loose spindle machines; and such machines in small sizes appeared to answer very satisfactorily.

Mr. J. STRACHAN said that with regard to the use of wire baskets, he had heard several complaints to the effect that when very delicate fabrics were being dried, the fabrics were burst by the pressure of the water forcing them between the wires. That had in some cases led to plate baskets being substituted for wire ones. The paper seemed to resolve itself more or less into an apology for the use of the wire basket. The author had referred to the Board of Trade requirements with regard to steam boilers, and he had drawn a very fair comparison between the steam boiler and high speed hydro-extractors. What would the Board of Trade say if an engineer were to submit to them a steam boiler, the shell-plates of which were tacked together with cold riveting and soft solder, like a wire basket? In theory, no doubt, wire was very satisfactory, but there were other points to be considered, viz. lateral and vertical stiffness, &c. How was it that the firm in whose employment the author was had abandoned wire baskets for high speed machines, and for sugar refineries, &c., used only steel plate baskets with riveted joints? At the present time, in sugar refineries there was practically one type of centrifugal machine, and that was a suspended machine of the Weston type, with a plate basket, and in nearly every case there was some modification of the suspended elastic bearing, to admit of the machines being worked at full speed on the third or fourth or fifth floor of a building without vibration. As far as his recollection went, the American system of making the basket with simple butt joints had not been very successful. A certain side strain was set up, which acted disadvantageously upon the plain butt joints. The author of the paper had very properly called attention to the greater efficiency of baskets of very small diameter, as compared with baskets of large diameter, when driven at the same peripheral speed. It was a peculiarity of all wire baskets in common use that they were exceedingly shallow in relation to their diameter. Plate baskets of 36 inches in diameter were made in practice about 21 inches deep; 36-inch wire baskets were only 13 inches deep. In common with other speakers, he should have liked to have heard more of the suspended self-balancing and elastic bearing machines, as they had been used for high speeds for many years, and were certainly superseding the antiquated fixed machines.

Mr. J. BERNAYS said he wished to emphasise the necessity of properly balancing centrifugal machines, but, as many present had probably given that point their principal attention, he would not expend many words upon it. As an illustration of the importance of properly balancing, he might mention that about twenty years ago he was called upon to collect and send abroad a complete set of machinery for the manufacture of a certain article, and a centrifugal machine with a copper basket was included. On one side the joints were riveted in the usual way, but the makers had forgotten to balance the basket, and the result was that when the machine was erected on a rigid foundation it shook not only the foundation but the whole building. The effect was discernible on the other side of the street, and the authorities made the manufacturer stop the machine until it was put right. What the manufacturer did was to put a balancing strip of copper opposite the joint of the basket. That addition very much reduced the vibration; but it was found after a short time that the basket itself was thereby thrown out of shape, inasmuch as it lost its rotundity, and one day the whole collapsed.

Mr. H. O'Connor said that some time ago he was present when some experiments were being made in the use of a cream separator for separating oil-gas tar and water. The tar had a very light specific gravity, having come from the manufacture of oil gas. The tar and water being very intimately mixed, it was very difficult to separate them by gravitation, and the separator certainly did not act. He believed there was an arrangement which was being used very successfully for ordinary coal tar, and he understood that it had been used for oil-gas tar, but he had not seen it. They now separated the oil-gas tar from the water by using it as a condensing material, and by continually passing it over the warm pipes the water was gradually made to separate itself to a certain extent from the tar in the form of steam, until the tar became sufficiently heavy to fall to the bottom.

The President said that the perfect balancing of the engines working the machines could be very well accomplished, if the result would warrant the expense, by putting two engines opposite one another on opposite sides of the crank-shaft, the pistons working outward and inwards simultaneously. The engines should be duplicates in every respect, and their employment would get rid entirely of the action due to the reciprocating portions of the engines. Reference had been made to the governors being much interfered with by tightening up the glands of the throttle valve spindles. Regulating valve spindles working through glands and having a reciprocating motion was nearly absolute, or ought to be. They should always work rotatively. The friction of the spindles was then reduced to a minimum. The best plan was to have some kind of link gear where but very slight friction took place. As to the question of balancing, it was very clear why Mr. Bernays' basket collapsed. If there was an amount of metal on one side to balance the joint on the other side, there would be two opposite forces tending to cause the basket to open out on those sides, and to close in a direction at right angles to the former, so it would thus become oval, and would ultimately collapse. That effect had not been previously referred to. On the score of strength, wire would be a very efficient material for baskets.

With regard to electric driving, there was no doubt a very large field for it in connection with centrifugal machines. With reference to the point of Mr. Paton, he (the President) could not suggest any means whereby the material could be discharged from the basket while the machine was at work; but he could suggest something whereby the power lost in stopping could be utilised, and that was by having a small motor fixed on the shaft in such a way that it would be put into gear when the basket was required to be brought to rest, when current could be generated, and stored in accumulators. Some years ago an attempt was made to utilise the energy lost in stopping tramcars. The act of stopping caused the coiling up of springs, which, on being released, helped to start the cars afterwards. This, however, had been abandoned.

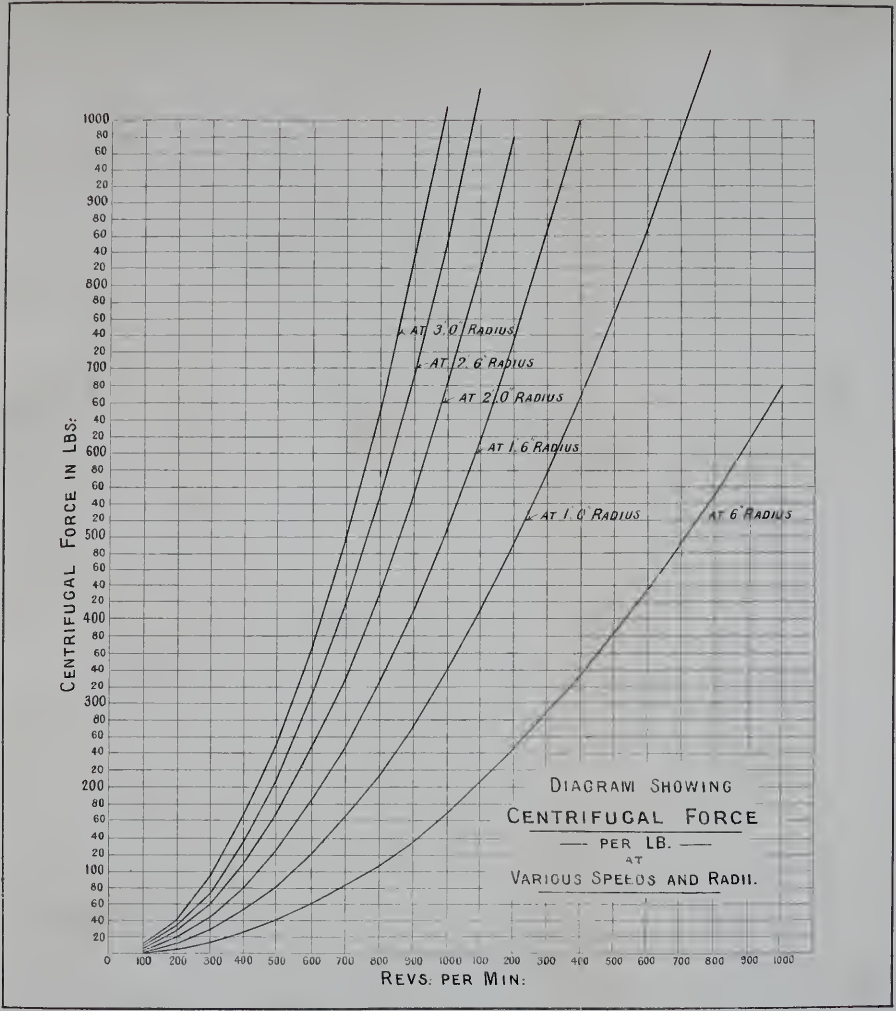
Mr. Ransom, in reply, said the discussion appeared to have resolved itself pretty much into a consideration of the relative merits of plate baskets and wire baskets. Both types had their supporters, and, of course, it was very difficult to draw any definite conclusions from the arguments which were used by those who were interested in the different kinds. At first sight it would seem that wire baskets ought to be far preferable to plate baskets, in consequence of the superior tensile strength of the former as compared with their weight. It was difficult in some respects to get sufficient vertical rigidity with wire, but experience had shown that wire baskets could be run for many years without showing signs of distortion. In support of that view he might quote a remark of Mr. Laidlaw, who had stated that some plate baskets were supported by a number of iron rings, and that they worked well. He took it that iron rings differed very little from ordinary stout wire.

Mr. Laidlaw said he had merely mentioned that a common practice in America at the present time was to take a plate and put hoops on, but not to depend on them for strength at all. He had not said that he advocated the method.

Mr. RANSOM said the balancing of engines was, of course, a subject in itself, and one upon which a great deal of work had been done during the last year or two in connection with torpedo boat engines; but the question was rather outside the general scope of the paper. The question of the calculations adopted had been raised by Mr. Hudson and Mr. Schönheyder. He thought that it was rather doubtful whether the calculations relating to steam boilers could be applied in precisely the same way to centrifugal baskets; but if there were any doubt it would be better to take the formula which gave the lower result, although he thought that perhaps there ought to be some remark on the table as to the mode in which the figures had been arrived at; and he would see that such an addition was made to the table. Some of the speakers appeared to refer to the figures given in the examples as if they had been taken from actual practice. They were simply approximate. Each example had been taken in precisely the same way and from the same data, and they were therefore of comparative interest rather than of actual value.

The President and several of the speakers had referred to engine governors, and had pointed out the rotary spindle in preference to one which reciprocated backwards and forwards through the gland. He quite agreed with that view, but it must not be forgotten that, even in glands in which the spindles had merely a rotary action, there was still a possibility of increasing the friction in the glands enormously. He believed that it was common in such cases to have a set-screw placed at the end of the spindle, and arranged in such a way that the pressure between two gun-metal cones would be increased by a trifling turn for the purpose of making a steam-tight joint. He had found that a comparatively small turn of such a screw would increase the friction, and, consequently, diminish the efficiency of the governor almost as much as would the ordinary stuffing-box gland which had to be tightened round the spindle which rose and fell through it. As the President had pointed out, it would be a great benefit if engines of the Corliss type could be used, but he believed that, as a matter of fact, they were used principally only in the larger sizes, and such engines were not commonly employed in establishments to drive centrifugals.

Turning again to the question of governors, he thought that it was an unfortunate thing that a very large proportion of those now on the market had the ordinary and most objectionable form of a stuffing-box and gland through which the spindle reciprocated. He had to thank the meeting for the attention which they had given to his paper, and for the discussion to which the paper had given rise.



F. & F. N. Spon, London & New York

Obituary.

WILLIAM SYMS, who died on the 15th of April, 1894, was born at Chatham on the 11th of November, 1820. In 1842 he was elected a member of the committee of the Chatham Mechanics' Institute, and was shortly afterwards appointed one of the secretaries, and a lecturer on meteorology, hydrostatics and cognate subjects. He held the appointment of auditor to the Chatham Water Company from its incorporation, and acted in the same capacity for several other local institutions, and was chairman of the late Chatham Local Board. In 1857 he was appointed secretary to the Rochester, Chatham and Strood Gas Light Company, which was then only a small concern. Later on he became its manager and engineer, and under him the undertaking proved a great success. Mr. Syms was a member of the Kent Archæological Society, the British Archæological Society, the Incorporated Gas Institute, the Institute of Gas Engineers, and the Southern District Association of Gas Engineers. He was elected a Member of the Society of Engineers in 1867.

GEORGE ERAUT, junior, who died on the 28th of May, 1894, was born at Wimpole, Cambridgeshire, on the 3rd of June, 1861. After completing his education at the Whitgift Grammar School, Croydon, at which, and at a private school previously, he gained distinction, he entered the office of Mr. Jabez Church, M.I.C.E., as a pupil, in May 1879. After his term of pupilage he remained with Mr. Church, subsequently becoming his chief assistant, and so remaining until June 1892, when he was appointed manager and secretary to the Braintree and Bocking Gas Company. During the time of his engagement with Mr. Church he assisted in the design and construction of numerous important gas and water works. Mr. Eraut was elected an Associate of the Society in December 1880.

THOMAS HOGG, whose death occurred on the 14th of June, 1894, and was the result of a fall, was born at Coombe, Surrey, on November the 16th, 1852. He was educated at Kingston Grammar School, and in 1869 was articled to Messrs. Manley & Rogers, builders and contractors, of London. After serving his time with that firm he was, in 1875, appointed clerk of the works to the Drapers' Company, London, and afterwards to the Middlesex Industrial School at Feltham. In 1879 he was appointed surveyor to the Improved Industrial Dwellings Company, which appointment he held at the time of his death. Mr. Hogg was elected an Associate of the Society in 1882.

Alfred Williams, who died on the 20th of July, 1894, was for many years closely identified with that branch of the profession which relates to gas engineering. He was one of the founders of the Society of Engineers, and occupied the position of Honorary Secretary and Treasurer from its inauguration in 1854. Mr. Williams was born in 1826, and was educated at Christ's Hospital. His professional career commenced by an engagement with the Horsley Iron Company, and amongst his early work was the superintendence of the erection of bridges over roadways on the Blackwall Railway. He subsequently superintended the erection of a gasholder at the Kennington Lane Station of the Phœnix Gas Company, which was at that time the largest gasholder in the world. After leaving the Horsley Company Mr. Williams entered the office of the late Mr. R. M. Christie, in conjunction with whom in 1860 he designed the Crystal Palace Gas-works, and subsequently the Croydon Gas-works, and in 1863 the Bromley (Kent) Gas-works. In course of time Mr. Williams became a partner with Mr. Christie under the style of Christie & Co., and upon the death of Mr. Christie he succeeded to the business, the name of the firm being in time changed to Alfred Williams & Co. He was at one time consulting engineer and contractor for the Eastbourne Gas Company, and constructed their new works. He also acted as consulting engineer to the North Middlesex Gas Company, Mill Hill, Hendon, and to the Grays Gas Company. He was engineer and contractor for the Georgetown (Demerara) Gas Company, and was Chairman of that Company at the time of his death. He was the contractor for the Ascot Gas-works and the Woking Gas-works, besides which he carried out a number of minor contracts.

His great services to the Society of Engineers are well known to all the Members. His position from first to last, for 40 years, has been that of Honorary Secretary and Treasurer, in which capacity his administrative talents placed him in the forefront as regards the development of the Society and the efficient conduct of its affairs. In course of time Mr. Williams' professional engagements obliged him relinquish some of the more clerical duties of the office which then devolved upon a paid Secretary. At that date, 1868, a testimonial was presented by the Members of the Society to Mr. Williams, consisting of a silver tea and coffee service and an appropriate address, in recognition of the untiring zeal and energy he had displayed in the successful management of the Society's affairs and the invariable courtesy with which the numerous duties of his office had been discharged. That zeal, energy and courtesy were displayed by Mr. Williams to the end of his life and he will ever remain a pleasant memory to those with whom he was associated in the management of the Society's affairs, and not less to those in the general body of Members with whom he was brought into personal contact.

A memorial portrait of Mr. Williams forms an appropriate frontispiece to the present volume of Transactions.

THOMAS MANSON RYMER-JONES, who died on the 26th July, 1894, was born on the 9th of December, 1839. He was educated at King's College, London, and in 1858 was articled to Mr. James Abernethy under whom he was engaged on the Falmouth Harbour and Dock Works. In 1862 he took charge of similar work at Devonport for Mr. Jackson, and was subsequently appointed one of the assistant engineers on the Madras Railway. After erecting some heavy iron girder bridges he was placed in charge of a district in the North-west Division. In 1871 Mr. Rymer-Jones was appointed one of the assistant engineers on the Mexican Railway, and in the following year he made surveys of the Smyrna and Cassaba Railway. In 1873 he was appointed one of the assistant engineers on the Imperial Government Railways of Japan, and was at first engaged on surveys and afterwards was entrusted with the construction of an extension line on which were some heavy works. In 1881 Mr. Jones returned to England and in 1883 he went to Central America to construct a railway, which line however was subsequently abandoned. He then returned to England and commenced practice as a consulting engineer and was so practising at the time of his death. Mr. Jones was elected a Member of the Society of Engineers in 1882, and in the same year he contributed a paper on railway travelling in Japan.

CHARLES CRESSY HORSLEY, who died on the 3rd of August, 1894, was born on the 24th of November, 1856. He was educated at King's College, London, and passed through the workshops there. In 1874, he was articled for three years to the late Mr. James Easton, C.E., of the firm of Easton & Anderson, Erith, and remained with him a year after he was out of his time. In 1878, he went to Messrs. C. Docwra & Sons and was engaged in the construction of the New River Company's filter beds at Hornsey, a large tank at the South Metropolitan Company's

Gas-works, and the sewage outfall at Crossness. In 1880 he became assistant to his father, under whom he carried out the outdoor engineering work for Messrs. James Oakes & Co., of the Alfreton Iron Works. Mr. Horsley was elected an Associate of the Society in 1875 and was transferred to the class of Members in 1885.

Henry Faija, who died on the 21st of August, 1894, after a protracted illness, was born in London in 1844, and was educated at University College School. He was subsequently articled to a firm of shipbuilders on the Thames. After occupying important positions in various shipbuilding yards in the north of England he commenced practice in London as an engineer in 1870. It was almost by an accident that he took up the subject of Portland cement, on which subject he eventually became such an authority. Having to design and erect a cement works, he was impressed with the crude and wasteful methods then adopted for producing cement. He therefore made a special study of the subject. About 1875 he established a Cement Testing Room and Laboratory in Westminster where cements and kindred materials were examined and reported upon. He was elected a Member of the Society in 1885, and at the time of his death was a Vice-President. In the same year that he was elected he read a paper on the mechanical examination and testing of Portland cement, which embodied the latest methods of examining cement to ascertain its constructive value. In 1888, when the magnesia scare occurred owing to the failures at Aberdeen, he read a paper before the Society with the view of disproving the idea then prevalent that the failures were due to the destructive effect of sea-water on Portland cement. The results of his experiments and deductions therefrom bore out his contention, that given a sound cement, and properly manipulated concrete, the effect of sea-water was not destructive. For this paper he was awarded the President's Premium. As a sequel to the above paper Mr. Faija made an exhaustive series of experiments on the forced percolation of sea-water through concrete, the results of which were embodied in a paper read before the Society in 1889, showing among other things that water percolated but very slowly even at a head of 22 feet and eventually ceased altogether. For this paper he was awarded a Society's premium.

As an inventor his efforts were marked by special ability, several ingenious inventions having been devised by him. One of the principal results of his researches in the examination of cement for the estimation of its constructive value, is his apparatus for determining its freedom from subsequent expansion, which by artificially accelerating the setting and hardening of a sample enables an opinion to be formed in twenty-four hours, which in the ordinary course would take at least a week. His chief work as an author is his handbook, 'Portland Cement for Users,' which was published in 1881.

Edward Cartwright Harvey, who died on the 13th of October, 1894, was born on the 29th of September, 1866, at Londonthorpe, near Grantham. He was educated at Besthorpe School near Newark, and afterwards served his time with Messrs. Richard Hornsby and Sons, agricultural engineers, Grantham. At the termination of his apprenticeship in 1888, he went out to Johannesburg on his own account, and was engaged by Messrs. Hornsby's firm out there. He subsequently obtained an appointment as chief engineer to the May Consolidated Gold Mining Company, and afterwards as resident engineer to Messrs. Howard Farrer & Co. on the Geldenhuis estate. About two years ago, owing to illness, he came over to England, and after recruiting his health he returned to his duties, but in the following year he resigned his appointment in consequence of the unsatisfactory state of his health, and again returned to England. At the latter end of last year he once more went out to Johannesburg, and last September he met with a serious accident in the mine and ultimately died from the effects of the injuries he received. He was elected a Member in 1892.

Edwin Davenport Latham, who died at Middlesbrough on the 21st November, 1894, and was elected a Member in 1868, was the youngest son of the late Mr. George Latham, of Nantwich, an eminent architect, and was born in 1843. Mr. Latham commenced his education at the Nantwich Grammar School, and completed it at an academy near Chester. He commenced his professional training in the same office as his brother, Mr. Baldwin Latham, C.E., and was for some years connected with the surveyor's department of his native town. He afterwards held professional appointments in Ely and Croydon. In 1865 he was appointed borough engineer to the Corporation of Bideford, North Devon, and was employed as engineer by the Northam Local Board. In 1869 he was appointed borough engineer of Middlesbrough, which appointment he held at the time of his death. In his official capacity he carried out many improvement works, both public and private, including main drainage works, the public park, fever hospitals, cemeteries, public baths and the like. About fifteen years ago, during a period of great commercial depression, at the request of the corporation, Mr. Latham undertook the management of the gas-works, which office he held for eleven years. During that time he reconstructed a large portion of the old gas-works plant and built entirely new works. So satisfactory was his management that on retiring from it he received the special thanks of the corporation.

George Garnett, whose death occurred on December 18th, 1894, was an old member of the Society, having been elected in 1868. Mr. Garnett was born in 1819, and was consequently in his 75th year when he died, his death resulting from an attack of apoplexy. He was educated at the Portsea Grammar School, and on finishing his education he came to London and entered a large drug establishment in the City, and was one of the founders of the Pharmaceutical Society of Great Britain. In course of time he returned to Portsea and continued in the same line of business for a few years, during which he wrote a series of articles on the manufacture of gas, which were published in the local journal. These articles having attracted attention, Mr. Garnett was offered and accepted an appointment with the Portsea Island Gas Company. In a short time, owing to a death on the staff, he was promoted to the post of manager, which position he held for ten years. In 1858, Mr. Garnett went to Ryde, Isle of Wight, and was appointed engineer and manager of the Ryde Gas Company, which position he occupied at the time of his death. Only a month previously to that occurrence the inauguration of a new gasholder at the Ryde works took place, upon which occasion Mr. Garnett played a prominent part. The deceased gentleman was largely consulted upon gas matters, especially with respect to its introduction into various towns. He identified himself with every movement tending to the welfare of Ryde, and amongst other offices he held there was that of chairman of the School Board. He was for two successive years president of the Gas Institute, and was also a member of the South-West of England Association and the Eastern Counties Association of Gas Managers.

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